(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 826 394 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
04.03.1998 Bulletin 1998/10

(51) Int. Cl.[6]: **A61N 5/10**

(21) Application number: 97114481.1

(22) Date of filing: 21.08.1997

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE

(30) Priority: 30.08.1996 JP 229699/96

(71) Applicant: HITACHI, LTD.
Chiyoda-ku, Tokyo 101 (JP)

(72) Inventors:
- Hiramoto, Kazuo
  Hitachioota-shi, Ibaraki 313 (JP)
- Akiyama, Hiroshi
  Hitachi-shi, Ibaraki 316 (JP)
- Matsuda, Koji
  Hitachi-shi, Ibaraki 319-12 (JP)

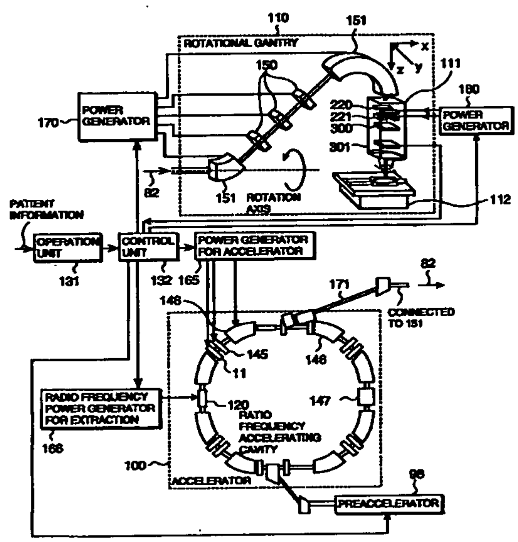
(74) Representative:
Strehl Schübel-Hopf Groening & Partner
Maximilianstrasse 54
80538 München (DE)

(54) Charged particle beam apparatus and method for operating the same

(57) A charged particle beam apparatus having a reduced loss of the charged particle beam, and a method for operation the same are provided.

In accordance with information such as a shape of affected part, and others, irradiation positions in a horizontal direction and a necessary irradiation dose are previously designated. An interval between the irradiation positions in the horizontal direction is desirably designated as smaller than a half of the charged particle beam size enlarged by a scatterer. A control unit controls a power source of electromagnets in order to change an irradiation position during stopping extraction of the charged particle beam. An affected part is irradiated with the charged particle beam per respective irradiation position. An irradiation target can be irradiated uniformly with the charged particle beam by overlapping the charged particle beam, because the irradiation dose of the charged particle beam enlarged by the scatterer has a Gaussian distribution in a radial direction centered at the irradiation position. In comparison with a case when the charged particle beam enlarged by a scatterer in order to cover all the region of the affected part, ununiformly irradiated region formed around the affected part can be minimized, and the loss of the charged particle beam can be reduced. In comparison with another case when the scatterer is not used, the number of changing the irradiation position is small because the size of the beam of the present invention is larger than the other case, and the controlling method can be simplified.

FIG.3



EP 0 826 394 A2

Description

Background of the Invention

One of th charged partid beam apparatus of the prior art is disclosed in JP-A-5-40479 (1993). The prior art is explained referring to FIG. 1.

In FIG. 1, the charged particle beam goes forward to the direction of Z. When sine wave current having a phase difference of 90 ° each from other is supplied to the X direction scanning electromagnet 80 and to the Y direction scanning electromagnet 81, respectively, the charged particle beam scans circularly by magnetic fields generated by the respective electromagnets. When the charged particle beam scanning circularly is projected onto a scatterer 83, the size of the charged particle beam is broadened, and the dose in an irradiation region is distributed as shown in FIG. 2. The dose becomes uniform in the region within the position of 2r, but the dose in the region outside the position of 2r decreases more as far as apart from the central position and becomes uneven. Accordingly, the uneven irradiation region was cut by a collimator, and only the irradiation region having an uniform dose was used for irradiating an affected portion.

The JP-A-7-275381 discloses a method, by which electromagnets are controlled so that the irradiation region is formed in an arbitrary shape.

Summary of the Invention

However, in accordance with the prior art, loss of the charged particle beam is significant, because the uneven irradiation region is eliminated by the collimator. Furthermore, in order to obtain a large irradiation field, the thickness of the scatterer 38 for increasing the size of the beam must be increased, and a problem to increase the loss of charged particle beam energy occurs.

One of the objects of the present invention is to provide a charged particle beam apparatus, wherein the loss of the charged particle beam is decreased, and a method for operating the same.

The present invention relates to a charged particle beam apparatus for utilizing the charged particle beam for cancer therapy, diagnosis of affected parts, and others.

The feature of the present invention to achieve the above objects is in the steps of broadening the size of the charged particle beam by a scatterer, switching the extraction of and stopping the charged particle beam by an extraction switching means, setting an irradiation position of the charged particle beam by an electromagnet, and changing the irradiation position or the irradiation range by controlling the electromagnet with a controlling apparatus during stopping the charged particle beam.

In accordance with the above feature, th uneven irradiation region around an irradiation target can be minimized and the loss of the charged particle beam can be reduced in comparison with a case, wherein the charged particle beam is enlarged by the scatterer so as to cover all the region of the irradiation target, because the controlling apparatus changes the irradiation position or the irradiation range during the extraction of the charged particle beam is stopped by the extraction switching means, and then, the irradiation target of the charged particle beam is irradiated per each of the irradiation positions or the irradiation range.

Furthermore, in comparison with a case when the scatterer is not used, the number of changing the irradiation position is small, and control is simple, because the size of the charged particle beam is large.

Another feature of the present invention is in changing the irradiation position on the basis of the size of the enlarged charged particle beam by the controlling apparatus. An even irradiation region having an uniform irradiation dose can be formed by overlapping the charged particle beams, and the irradiation target can be irradiated uniformly with the charged particle beam, because the irradiation dose of the charged particle beam, which is enlarged by the scatterer, distributes diametrically in approximately a Gaussian distribution with a center at the irradiation position.

Another feature of the present invention is in the steps of being decided a target of the irradiation dose in the irradiation region of the irradiation target by an apparatus for setting the target of the irradiation dose, determining the irradiation dose of the charged particle beam in the respective irradiation regions by an irradiation does measuring apparatus, and switching the extraction and stopping the charged particle beam by an extraction switching means on the basis of the target of the irradiation dose and the observed irradiation dose determined by the irradiation does measuring apparatus.

In accordance with the above feature, the target of the irradiation can be irradiated with an uniform beam density even if the intensity of the beam varies depending on time, because the irradiation can be continued by the extraction switching means until the irradiation dose at the irradiation region reaches the target of the irradiation dose.

When the extraction switching means is a radio frequency supplying apparatus for supplying radio frequency electromagnetic field including frequencies of bettor oscillation of the charged particle beam, which circulates in the charged particle accelerator, to the charged particle beam, the amplitude of the bettor oscillation of the charged particle beam is increased by supplied radio frequency electromagnetic field when the bettor oscillation of the charged particle beam circulating the charged particle accelerator is in a resonance condition, and the charged particle beam is extracted from the charged particle accelerator by exceeding a stability limit of th resonance. At this time, since the

charged particle beam is extracted with a constant rate, the irradiation target is irradiated with the charged particle beam with an uniform beam density.

Another feature of the present invention is in changing the energy of the charged particle beam by energy varying means, and the irradiation rang of the irradiation target can be changed by varying the energy of the charged particle beam during stopping the irradiation.

Another feature of the present invention is in that the charged particle accelerator is provided with an extraction switching means for switching the extraction and stopping the charged particle beam, a charged particle beam transport system is provided with a transportation switching apparatus for switching the transportation and stopping the charged particle beam, and the irradiation apparatus comprises a scattered for enlarging the charged particle beam, an electromagnet for setting the irradiation position of the charged particle beam, and a controlling apparatus for varying the irradiation position based on the size of the enlarged charged particle beam.

In accordance with the above feature, the charged particle beam is irradiated to the irradiation target with the irradiation apparatus by extracting the charged particle beam which is circulating the charged particle accelerator to the irradiation apparatus by the extracting switching means, and transporting the charged particle beam to the irradiation apparatus by the transportation switching apparatus. The irradiation of the charged particle beam to the irradiation target is stopped by stopping the extraction of the charged particle beam from the charged particle accelerator to the irradiation apparatus by the extraction switching means, or stopping the transportation of the charged particle beam by the transportation switching apparatus. Desirable safety can be ensured, because the switching of the irradiation can be performed by two switching means different from each other. When the extraction switching means, or the transportation switching apparatus terminates the extraction of the beam, the controlling apparatus varies the irradiation position to the next point based on the size of the charged particle beam which is enlarged by the scatterer, and the irradiation is performed with an equal dose at every irradiation positions, the charged particle beam is partly overlapped to form an irradiation region of an uniform irradiation dose, and the irradiation target can be irradiated with the charged particle beam uniformly, because the irradiation dose of the charged particle beam which is enlarged by the scatterer has a Gaussian distribution in the radial direction with a center at the irradiation position.

Furthermore, since the uneven irradiation region formed surrounding the uniform irradiation region can be reduced, the loss of the charged particle beam can be decreased. In comparison with a case when the scatterer is not used, the number of changing the irradiati n position can be reduced, because the size of the beam is larger than the case no scatterer is used, and controlling can be simplified.

Another feature of the present invention is in being provided with a movement detecting means for detecting the movement of patient, and controlling the extraction switching means based on the movement of th patient detected by the movement detecting means by the controlling apparatus.

In accordance with the above feature, the irradiation target can be irradiated precisely, because the irradiation of the charged particle beam is performed when the patient is almost still by detecting the movement of body of the patient caused by breathing and coughing with the movement detecting means.

In a case of cancer therapy by the charged particle beam, the energy of the charged particle beam must be changed depending on the depth of the irradiation target. In this case, the energy of the charged particle beam circulating in the charged particle accelerator is changed in an accelerating step, or the energy of the extracted charged particle beam is changed by placing a plate-shaped material such as graphite at a path of the charged particle beam in the irradiation apparatus.

Another feature of the present invention is in the steps of broadening the size of the charged particle beam by a scatterer, extracting the charged particle beam from a charged particle accelerator by an extraction means, setting an irradiation position or an irradiation range of the charged particle beam by an electromagnet, and changing the irradiation position or the irradiation range by controlling the electromagnet with a controlling apparatus during any one of operations of injection, acceleration, and deceleration of the charged particle accelerator.

In accordance with the above feature, the uneven irradiation region around an irradiation target can be minimized and the loss of the charged particle beam can be reduced in comparison with a case, wherein the charged particle beam is enlarged by the scatterer so as to cover all the region of the irradiation target, because the controlling apparatus changes the irradiation position or the irradiation range during any one of operations of injection, acceleration, and deceleration of the charged particle accelerator after the extraction by the extraction means, and then, the irradiation target of the charged particle beam is irradiated per each of the irradiation positions or the irradiation range.

Furthermore, in comparison with a case when the scatterer is not used, the number of changing the irradiation position is small, and control is simple, because the size of the charged particle beam is large.

Another feature of the present invention is in the steps of broadening the size of the charged particle beam by a scatterer, moving the charged particle beam to an extracting orbit from a circulating orbit by a kicker electromagnet, setting an irradiation position or an irradiation range of the charged particle beam by an electromagnet, and changing the irradiation position or the irradiation range by controlling the electromagnet with a

controlling apparatus during any one of operations of injection, acceleration, and deceleration of the charged particle accelerator.

In accordance with the above feature, the uneven irradiation region around an irradiation target can be minimized and the loss of the charged particle beam can be reduced in comparison with a case, wherein the charged particle beam is enlarged by the scatterer so as to cover all the region of the irradiation target, because the controlling apparatus changes the irradiation position or the irradiation range while the beam is not extracted during any one of operations of injection, acceleration, and deceleration of the charged particle accelerator after the extraction as the result that the kicker electromagnet moves the charged particle beam to an extraction orbit from a circulating orbit, and then, the irradiation target of the charged particle beam is irradiated per each of the irradiation positions or the irradiation range.

Furthermore, in comparison with a case when the scatterer is not used, the number of changing the irradiation position is small, and control is simple, because the size of the charged particle beam is large. Furthermore, an even irradiation region having an uniform irradiation dose can be formed by overlapping the charged particle beams, and the irradiation target can be irradiated uniformly with the charged particle beam, because the irradiation dose of the charged particle beam, which is enlarged by the scatterer, distributes diametrically in approximately a Gaussian distribution with a center at the irradiation position.

The beam is extracted as soon as the kicker electromagnet is excited, and the extraction can be completed almost while the beam circulates only one round in the accelerator because the time of being excited is one circulation time or so. Then, the charged particle beam, which is extracted in such a short time as about one circulation time of the beam, can be used continuously.

Brief Description of the Drawings

FIG. 1 is a schematic diagram showing a conventional charged particle beam apparatus,

FIG. 2 is a graph indicating an intensity distribution of the beam enlarged by the conventional charged particle beam apparatus,

FIG. 3 is a schematic diagram showing the first embodiment of a charged particle beam apparatus of the present invention,

FIG. 4 is a graph indicating an intensity distribution of the beam enlarged by a scatterer,

FIG. 5 is a graph indicating an example of the relationship between depth of an effected part and irradiation dose of an ion beam,

FIG. 6 is a schematic illustration indicating the irradiation nozzle 111 of the first embodiment,

FIG. 7 is a block diagram of an operating unit 131 of the first embodiment,

FIG. 8 is a perspective view showing layers and irradiation regions of an affected part in the first embodiment,

FIG. 9 is a flow chart showing the first embodiment of a method for operating the medical charged particle beam apparatus,

FIG. 10 is a schematic diagram showing a charged particle beam apparatus using a cyclotron 172,

FIG. 11 is a perspective view showing layers and irradiation regions of an affected part in the second embodiment,

FIG. 12 is a flow chart showing the method for operating the medical charged particle beam apparatus of the second embodiment,

FIG. 13 is a schematic illustration indicating the irradiation nozzle 111 of the third embodiment,

FIG. 14 is a flow chart showing the method for operating the medical charged particle beam apparatus of the third embodiment,

FIG. 15 is a schematic diagram showing the fourth embodiment of a charged particle beam apparatus of the present invention,

FIG. 16 is a flow chart showing the method for operating the medical charged particle beam apparatus of the fourth embodiment,

FIG. 17 is a schematic diagram showing the fifth embodiment of a charged particle beam apparatus of the present invention, and

FIG. 18 is a flow chart showing the method for operating the medical charged particle beam apparatus of the fifth embodiment,

Detailed Description of the Preferred Embodiments

(Embodiment 1)

Referring now to FIG. 3, the first embodiment of a charged particle beam apparatus according to the present invention is described hereinafter.

The charged particle beam apparatus of the present embodiment mainly includes a pre-accelerator 98, an accelerator of synchrotron type 100, a rotational gantry 110, an operation unit 131 and a control unit 132. Ions of low energy from the pre-accelerator 98 are injected into the accelerator 100 and they are accelerated by the accelerator 100 and then extracted to the rotational gantry 110 inside a treatment room so that an ion beam may be used for medical treatment.

Main components constituting the accelerator 100 will be descried. The accelerator 100 is an accelerator utilizing the diffusion resonance extraction method for beam extraction in which betatron oscillation of a charged particle beam circulating through the accelerator 100 is brought into a resonance state and a radio frequency electromagnetic field is applied to the circulating charged particle beam to increase the betatron oscillation thereof to thereby ensure that a stability limit of res-

onance can be exceeded and the charged particle beam can be extracted from the accelerator.

The accelerator 100 includes a bending electromagnet 146 for bending the circulating charged particle beam, a radio frequency accelerating cavity 147 for applying energy to the circulating charged particle beam, a quadrupole electromagnet 145 and a multipole electromagnet 11 for magnetic fields to the circulating charged particle beam to generate the stability limit of the resonance of the betatron oscillation, and a radio frequency applying unit for extraction 120 which applies a radio frequency to the circulating charged particle beam to increase the betatron oscillation. The accelerator 100 further includes a power generator for acceleration 165 which supplies current to the bending electromagnet 146, quadrupole electromagnet 145, and multipole electromagnet 11 which supplies electric power to the radio frequency accelerating cavity 147, and a radio frequency generator for extraction 166 which supplies electric power to the radio frequency applying unit for extraction 120.

The patient is irradiated by the beam extracted from the accelerator 100 and transported to the treatment room by the transport system 171 with the rotational gantry 110.

The rotational gantry 110 will be described hereinafter. The rotational gantry 110 includes quadrupole electromagnets 150 and bending electromagnets 151 which are adapted to transport a beam extracted from the accelerator 100 to an irradiation target, and a power generator 170 for supplying current to the quadrupole electromagnets 150 and the bending electromagnets 151.

The rotational gantry 110 further includes an irradiation nozzle. The irradiation nozzle includes electromagnets 220 and 221 which are provided downstream of one of the bending electromagnets 151 and operative to deflect the extracted beam in x and y directions. Here, the x direction is parallel to the bending plane of the one bending electromagnet 151 and the y direction is vertical to the bending plane of the one bending electromagnet 151. The electromagnets 220 and 221 are connected with a power generator 160 for supplying current to them. A scattered 300 for enlarging the size of the beam is provided at downstream of the electromagnets 220 and 221. A irradiation dose monitor 301 for determining the irradiation dose distribution of the beam is installed at further downstream of the scatterer 300. A collimator 225 is installed before the patient, an irradiation target, in order to prevent the normal tissue around the affected part from irradiation damage.

A beam intensity distribution 302 enlarged by the scatterer 300 is indicated in FIG. 4. the beam enlarged by the scatterer has approximately a Gaussian distribution. Accordingly, if the irradiation position is shifted about a half of the beam size, which is enlarged by the scatterer 300, as shown in FIG. 4 during the extraction of the beam from the accelerator is stopped, and an equivalent irradiation is resumed at each of the shifted positions, almost similar irradiation dose 303 can be obtained at any places including the places other than the irradiation center position of the beam by overlapping the irradiation. Therefore, an affected part can be irradiated uniformly by repeating the consecutive steps of confirming by the irradiation dose monitor 301 that the irradiation dose predetermined by the therapy plan is irradiated, the extraction of the beam from the accelerator is stopped, the irradiation position is shifted, and the extraction of the beam is resumed.

On the other hand, the region outside by 2r from the center of the irradiation is irradiated unevenly. However, the area of the uneven region is smaller in comparison with a case when an irradiation region having an uniform irradiation dose is realized by circular scanning of the charged particle beam in the irradiation region 2r.

Therefore, loss of the charged particle beam can be reduced. Furthermore, since the size of the beam enlarged by the scatterer 300 is smaller than the size of the beam when the circular scanning of the charged particle beam is performed, the thickness of the scatterer 300 can be decreased. Therefore, the energy loss of the charged particle beam can be reduced.

An example of a relationship between depth in a body and the irradiation dose of the ion beam is indicated in FIG. 5. The peak of the irradiation dose in FIG. 5 is called Bragg peak. The position of the Bragg peak varies depending on the beam energy. Therefore, a range shifter 222 and a ridge filter 223 for adjusting the energy and the energy width of the beam, and a patient bolus 224 for changing the energy depending on the depth, direction, and shape of the affected part are provided as shown in FIG. 6. The ridge filter 223 has a structure forming a saw teeth shape in the x direction in FIG. 6. The particle passed through the peak portion of the saw teeth is more reduced in the energy, and the particle passed through the bottom portion of the saw teeth is less reduced in the energy.

Therefore, an energy distribution based on the height of the peak portion and the depth of the bottom portion can be given to the beam. In the present embodiment, the ridge filter which makes the energy width of the charged particle beam coincide with a position where the affected part is deepest is used.

The operation unit 131 is an unit for determining data necessary for the control unit 132 to control the irradiation of the charged particle beam on the affected part.

The control unit 132 is an unit for controlling the extraction of the charged particle beam from the preaccelerator 98 into the accelerator 100, the acceleration of the charged particle beam circulating through the accelerator 100, the extraction of the charged particle beam from the accelerator 100 into the rotational gantry 110, and the transport of the charged particle beam in the rotational gantry 110.

Th r le of the operation unit 131 will first be

described and a method for operating the charged particle beam apparatus by means of the control unit 132 will then be described.

Affected part information such as shape and depth of the affected part, necessary irradiation dose R and information on the scatterer 300 such as thickness, materials, and so on is input to the operation unit 131 by an operator. On the basis of the input of the affected part information and the scatterer information, the operation unit 131 calculates and determines the size of the beam, the irradiation region, the energy of the charged particle beam to be irradiated on the affected part, and the magnitude of current to be supplied to the electromagnets 220 and 221.

The operation unit 131 is shown in FIG. 7. An irradiation former 133 of the operation unit 131 divides the affected part into a plurality of layers, as generally designated by Li (i= 1, 2, ...N), in the depth direction on the basis of the input affected part information, as shown in FIG. 8. An energy calculator 134 determines beam energy levels, as generally designated by Ei, suitable for irradiation in accordance with depths of the individual layers.

Further, the irradiation region former 133 determines a plurality of irradiation regions as generally designated by Ai,j(i=1, 2, ...N, j=1, 2,...N), center points Pi,j of the irradiation regions Ai,j, and coordinate values (xij, yij) of the center points in accordance with shapes of the individual layers Li. Since the intensity of the charged particle beam is spatially distributed pursuant to Gaussian distribution, the operation unit 131 determines the individual irradiation regions Ai,j and their center points Pi,j on the basis of the size of the charged particle beam so as to form irradiation regions wherein the irradiation doses are made uniform by overlapping the irradiation region Ai,j with adjacent irradiation regions. Each of the center points Pi,j is separated each from other approximately a half of the size of the beam.

An irradiation dose calculator 135 determines targets of irradiation dose at the individual center points Pi,j on the basis of the necessary irradiation dose Ri,j.

An electromagnet current calculator 136 determines current IXij and IYij supplied to the electromagnets 220 and 221 in order that the center of the charged particle beam matches the individual center points Pi,j.

The operation unit 131 delivers to the control unit 130 beam energy Ei, individual irradiation regions Ai,j, center points Pi,j, coordinate values (xij, yij) of the center points Pi,j, targets of irradiation dose Ri,j, and current IXij and IYij, which are determined in respect of the individual layers Li.

A method of operating the charged particle beam apparatus of the present embodiment is shown in FIG. 9.

(1) Th control unit 132 controls the power generator 170 to cause it supply current to the quadrupole lectromagnets 150 and the bending electromagnets 151 in order that the charged particle beam extracted from the accelerator 100 into the rotational gantry 110 is transported to an affected part standing for the irradiation target.

(2) The accelerator control unit 132 controls the pre-accelerator 98 to cause it to eject a charged particle beam.

(3) The control unit 132 supplies current to the bending electromagnet 146, quadrupole electromagnet 145, and the multipole electromagnet 11 in order to accelerate the circulating charged particle beam to the energy level Ei, and controls the power generator for accelerator 165 to cause it to supply electric power to the radio frequency accelerating cavity 147.

(4) When the circulating charged particle beam is accelerated to the energy level Ei, the control unit 132 controls the power generator for accelerator 165 to cause it to supply current to the quadrupole electromagnet 145 and the multipole electromagnet 11 in order to generate the stability limit of the resonance of betatron oscillation.

When the electric power is supplied to the radio frequency applying unit for extraction 120, the betatron oscillation amplitude of the circulating charged particle beam increases, and this results in the resonance state of the betatron oscillation for the charged particle beam outside the stability limit.

(5) The control unit 132 controls the power generator 160 to cause it to supply current IXij and IYij to the electromagnets 220 and 221 in order that the center of the charged particle beam matches an optional center point Pi,j.

(6) The control unit 132 compares a target of irradiation dose Ri,j with an irradiation dose at the particular center point Pi,j measured by the irradiation dose monitor 301.

(7) When the irradiation dose at the particular center point Pi,j does not reach the target of irradiation dose Ri,j, the control unit 132 controls the radio frequency power generator for extraction 166 to cause it to supply electric power to the radio frequency applying unit for extraction 120 in order to start the extraction from the accelerator 100 to the rotational gantry 110.

When electric power is supplied to the radio frequency applying unit for extraction 120, a radio frequency electromagnetic field is applied to the circulating charged particle beam to increase the betatron oscillation amplitude of the circulating charged particle beam. When the betatron oscillation amplitude is increased until a stability limit of resonance of the betatron oscillation is exceeded, the charged particle beam is extracted from the accelerated 100 into the rotational gantry 110. In the rotational gantry 110, the charged particle beam is irradiated on an optional irradiation region Ai,j.

(8) The control unit 132 compares a target of irradiation dose Ri,j with an irradiation dose at another center point Pi,j measured by the irradiation dose monitor 301. When the irradiation dose at th center point Pi,j does not reach the target of irradiation dose Ri,j, the extraction is continued.

(9) When the irradiation dose at the different center point Pi,j reaches the target of irradiation dose Ri,j, the control unit 132 controls the radio frequency power generator for extraction 166 to cause it to switch off the extraction. Then, the irradiation control unit 130 controls the power generator 160 such that the center of the charged particle beam matches a center point Pi,j+1 of next irradiation region Ai, j+1.

(10) When the beam circulating through the accelerator 100 is sufficient for use at the time that irradiation on the irradiation region Ai,j shifts to irradiation on the irradiation region Ai,j+1, the operation is carried out starting with the step (4), but when the beam intensity and the extraction time are insufficient, the operation is carried out starting with the step (1) for the purpose of replenishing the charged particle beam.

(11) When the irradiation doses reach the targets at all irradiation regions Ai,j of an optional layer Li, the operation starting from the step (1) is carried out for next layer Li+1, and all irradiation regions Ai,j+1 are irradiated in a manner similar to that in the case of the layer Li.

(12) When irradiation on all the layers Li of the affected part are completed, the operation of the charged particle beam apparatus ends.

In accordance with the above embodiment, the layer Li of the affected part can be irradiated with an uniform irradiation dose. Since the uneven irradiation region formed outside a boundary of the layer Li of the affected part is cut off by the collimator 225, the irradiation of the charged particle beam fitting to the shape of the affected part can be performed. Since the cut off region is smaller in comparison with the cut off region of the conventional case wherein circular scanning of the charged particle beam is performed, the therapy irradiation can be performed with a smaller beam loss. Although the irradiation position of the charged particle beam has been set by two electromagnets, the irradiation position can be set by making the patient bed 112 have a movable structure, and controlling it by the control unit 132.

If the scatterer 300 is not used, the size of the irradiated charged particle beam is small. Therefore, intervals between respective of irradiation positions must be determined to be extremely small in order to obtain an uniform irradiation intensity distribution, and the therapy plan and the control of the irradiation become significantly complex. In accordance with the present embodiment using the scatterer 300, the charged particle beam has an approximately Gaussian distribution, and the size of the beam can be increased to an adequate area. Therefore, an uniform irradiation dose distribution can be realized without determining the intervals between the respective of irradiation positions extremely small.

As explained above, the charged particle beam apparatus of the present embodiment can form an uniform irradiation field with reducing the loss of the charged particle beam.

According to the present embodiment, even when the irradiation target has a complicated shape, the affected part can be irradiated with a high accuracy. Furthermore, since the irradiation is continued until the irradiation dose reaches a target, the affected part can be irradiated with uniform beam density even when the beam intensity changes with time.

Although a synchrotron was used as the accelerator in the present embodiment, a cyclotron 172 can be used as the accelerator as shown in FIG. 10. The extraction of and stopping the beam from the cyclotron 172 are performed by controlling the power source of deflector 174 for the deflector 175 with signals from the control unit 132, and supplying and terminating the charged particle beam from an ion source 173.

(Embodiment 2)

Next, a second embodiment of the present invention will be described. Component construction of the present embodiment is similar to that of the first embodiment. In the present embodiment, however, each layer Li of an affected part is not divided in the x direction but is divided only in the y direction as shown in FIG. 11. In other words, irradiation regions Ai,j are each wide in the x direction. Another irradiation region Ai,j is irradiated by changing the strength of a magnetic field generated by the electromagnet 220 to scan the charged particle beam in the x direction.

The operation unit 131 determines a central point Pi,j of each of the irradiation positions Ai,j based on the size of the charged particle beam so as to form regions of an uniform irradiation dose by overlapping the irradiation region Ai,j with adjacent irradiation regions. The respective of the central points Pi,j is separated each from other by almost a half of the size of the beam.

The operation unit 131 determines magnitude ΔIXij necessary for changing the magnetic field strength of the electromagnet 220 on the basis of an extent of each region Ai,j in the x direction. As in the case of embodiment 1, the operation unit determines the beam energy Ei, individual irradiation regions Ai,j, their center points Pi,j (xij, yij), targets of irradiation dose Rij, and current IXij and IYij in respect of the individual layers Li, and delivers them, together with the ΔIXij, to the control unit 132.

A method of operating the charged particle beam apparatus of the pres nt embodiment is shown in FIG.

12. Excepting the step (7), operation steps are the same as those of the first embodiment.

In the step (7), the control unit 132 controls the radio frequency power generator for extraction 166 to cause it to supply electric power to the radio frequency applying unit for extraction 120 in order that the extraction from the accelerator 100 into the rotational gantry 110 is started, and besides, controls the power generator 160 such that current IXij to the electromagnet 220 changes within a range of ΔIXij to cause the charged particle beam to be irradiated while being scanned in the x direction.

While in the present embodiment, the strength of the magnetic field generated by the electromagnet 220 is changed to scan the charged particle beam in the x direction and irradiate it on the irradiation region Ai,j, the charged particle beam may be irradiated while being scanned in the y direction by changing the strength of the magnetic field generated by the electromagnet 221.

In accordance with the present embodiment, the same advantages with the first embodiment can be obtained, and furthermore, the irradiation time can be shortened in comparison with the first embodiment, because the extraction of and stopping the charged particle beam can be switched by only in they direction (or the x direction).

(Embodiment 3)

Next, the third embodiment of the present invention is explained. In accordance with the present embodiment, the charged particle beam apparatus composed in the same manner as the apparatus shown in FIG. 3, except the composition of the irradiation nozzle 111 and the control unit for the same 132. The irradiation nozzle 111 of the present embodiment is shown in FIG. 13.

In the present embodiment, the scatterer 300 is made thinner than that in the first embodiment. Since the size of the charged particle beam enlarged by the scatterer 300 becomes smaller than that in the first embodiment, the number of irradiation regions Ai,j is increased. On the other hand, since the size of the charged particle beam is small, the patient collimator, which has been used in the first embodiment, is not used in the present embodiment. Similarly, since the size of the beam becomes smaller than that in the first embodiment, the ridge filter and the bolus, which have been used in the first embodiment, are not used.

In accordance with the first embodiment, the energy of the charged particle beam is made as Ei by the accelerator 100. However, in accordance with the present embodiment, the energy of the charged particle beam is made Ei by changing the thickness of the range shifter 222 during the extraction of the beam from the accelerator 100 is stopped by the control unit 132.

A method of operating the charged particle beam apparatus of th present embodiment is shown in FIG. 14. The method is the same as that in the first embodiment except the steps (3) and (4).

(3) The control unit 132 controls the power generator for accelerator 165 so as to supply current to the bending electromagnet 146, quadrupole electromagnet 145, and to supply electric power to the radio frequency accelerating cavity 147 in order to accelerate the circulating charged particle beam to the energy level E which is larger than the respective energy level Ei of the layers.

(4) When the circulating charged particle beam is accelerated to the energy level E, the control unit 132 controls the power generator for accelerator 165 to cause it to supply currents to the quadrupole electromagnet 145 and the multipole electromagnet 11 in order to put the betatron oscillation of the circulating charged particle beam into a resonance state.

As described above, the charged particle beam apparatus of the present embodiment can reduce the loss of the charged particle beam, and can form an uniform irradiation field. The affected part can be irradiated precisely without using the collimator or a bolus per respective patient.

In accordance with the present embodiment, the irradiation is performed by repeating change of the intensity of the electromagnets 220,221 for setting the irradiation position in a condition of a definite irradiation depth by setting the thickness of the range shifter at a definite length. After irradiating a layer of the definite depth, the thickness of the range shifter is changed, and the irradiation is repeated by the same steps as above. However, the irradiation can be performed by another method, wherein the target is divided supposedly into layers in parallel to the moving direction of the charged particle beam, the irradiation is performed in a condition of a definite intensity of the electromagnets 220, 221, then, the irradiation is stopped, the thickness of the range shifter is changed, and the irradiation is repeated. After irradiating a layer, the intensity of the electromagnets 220, 221 is changed, and the irradiation is repeated by the same steps as above.

(Embodiment 4)

The fourth embodiment of the present invention is explained hereinafter. The component composition of the present embodiment is shown in FIG. 15. Different points from the embodiment 1 are being provided with a movement monitor 250 for detecting the movement of the patient's body, and an electromagnet 177 for switching transportation of and stopping the charged particle beam and a power source 176 for the same in a beam transport system 171 for transporting the charged particle beam to the irradiation apparatus. Other components in the composition is as same as the embodiment 1. The power source 176 is arranged so that the beam

is not irradiated to the patient when electric current is not flowed by failure of the power source, and the beam is irradiated to the patient only when the electric current is supplied normally.

The movement monitor 250 can be a strain gauge provided at surface of the body, or a camera for detecting the movement of the patient. In accordance with a signal from the movement monitor 250, the movement of the patient's body is detected, and a signal to irradiate the beam to the patient's body is transmitted to the radio frequency power generator for the extraction 166 and the power source 176 for the switching electromagnet 177 of the beam transport system, only when the movement of the patient's body is in a still condition. Only when the above signal is positive for the irradiation, the radio frequency power generator for the extraction 166 provides high frequency to the charged particle beam, and the power source 176 supplies electric current to the switching electromagnet 177 of the beam transport system so that the charged particle beam is supplied to the rotational gantry 110. The operation method in the present embodiment is shown in FIG. 16. The operation steps is as same as the embodiment 1 except the steps (7) and (9).

In the step (7), when the irradiation dose at the particular center point Pi,j does not reach the target of irradiation dose Ri,j, and the patient is determined to be in a still condition by the signal from the movement monitor 250, the control unit 132 controls the radio frequency power generator for extraction 166 to cause it to supply electric power to the radio frequency applying unit for extraction 120 in order to start the extraction from the accelerator 100 to the rotational gantry 110. Concurrently, electric current is supplied to the switching electromagnet 177 in the charged particle beam transport system from the power source 176. However, if the patient is not determined to be in a still condition, the radio frequency power generator for extraction 166 and the power source 176 for the switching electromagnet 177 in the charged particle beam transport system are controlled so that the supply of the charged particle beam to the rotational gantry 110 is stopped.

In the step (9), when the irradiation dose at the particular center point Pi,j reaches the target of irradiation dose Ri,j, the control unit 132 controls the radio frequency power generator for extraction 166 to terminate the extraction of the charged particle beam, and the power source 176 to stop supplying the electric current to the switching electromagnet 177 in the charged particle beam transport system in order to terminate supplying the charged particle beam to the rotational gantry 110. Then, the power source 160 is controlled so that the center of the charged particle beam is adjusted to the center point Pi,j+1 of the next particular irradiation region Ai,j+1.

In accordance with the present embodiment, the same advantages as th advantages of embodiment 1 can be obtained, and additionally, the advanced safety can be obtained, because the switching of the irradiation is performed by two switching means. Furthermore, the irradiation target can be irradiated precisely, because the affected part can be irradiated with the charged particle beam when it is almost in a still condition.

(Embodiment 5)

The fifth embodiment is explained hereinafter. The composition of the apparatus of the present embodiment is shown in FIG. 17. The difference of the composition of the apparatus from the embodiment 1 is in using kicker electromagnet for extraction 121 for extracting the beam from the accelerator. The kicker electromagnet 121 extracts the circulating beam to the transport system 171 by being pulse-excited with the power source 167 of the kicker electromagnet by signals from the control unit 132. Therefore, the beam is extracted as soon as the kicker electromagnet 121 is excited, and the beam extraction can be completed almost while the beam circulates only one round in the accelerator. The division of the affected part is performed as same as the embodiment 1, as shown in FIG. 8.

The method of operation of the present embodiment is shown in FIG. 18. In the step (1), a magnitude of magnetic excitation of the electromagnet of the rotation gantry 110 is set so that the charged particle having the energy Ei can be transported in accordance with the signal from the control unit 132. Subsequently, the injection of the beam from the pre-accelerator 98 to the accelerator 100 and the acceleration and extraction of the beam are repeated by the steps (2) to (5). The beam is extracted as soon as the kicker electromagnet is excited, because the extraction is performed by the kicker electromagnet 121 in the present embodiment. Therefore, when the irradiation dose for respective partial region Ai,j is judged to be insufficient in the step (6), the injection, acceleration, and extraction of the beam is repeated further. Then, when the irradiation dose at the partial region Ai,j is judged as reaching the target irradiation dose in the step (6), the current IXi,j, IYi,j of the electromagnets for setting the irradiation position 220, 221 are varied so as to change the irradiation position by the signal from the control unit 132 in the step (4). When the irradiation of a layer Li is judged to be completed in the step (7), the injection, acceleration, and extraction of the beam are repeated with changing the irradiation layer until the irradiation of all the layers is judged to be completed in the step (8).

Claims

1. A charged particle beam apparatus, comprising a charged particle accelerator, for irradiating an irradiation target with charged particle beam supplied from said charged partic accelerator, further com-

prising:

a scatterer for enlarging the size of the charged particle beam,
an extraction switching means for switching on and off of said charged particle beam,
electromagnets for setting an irradiation position of said charged particle beam, and
a control unit for changing said irradiation position by controlling said electromagnets during said charged particle beam is switched off.

2. A charged particle beam apparatus as claimed in claim 1, wherein

said control unit changes said irradiation position based on the enlarged size of the charged particle beam.

3. A charged particle beam apparatus, comprising a charged particle accelerator, for irradiating an irradiation target with charged particle beam supplied from said charged particle accelerator, further comprising:

a scatterer for enlarging the size of the charged particle beam,
an extraction switching means for switching on and off of said charged particle beam,
electromagnets for setting an irradiation position of said charged particle beam, and
a control unit for maintaining a magnetic intensity of said electromagnets, or a variation range of the magnetic intensity of said electromagnets during the extraction of the charged particle beam substantially at a constant value or a constant range, and changing said irradiation position by controlling said electromagnets during the extraction of said charged particle beam is stopped.

4. A charged particle beam apparatus as claimed in claim 3, wherein

said control unit changes said magnetic intensity, or said variation range based on the enlarged size of the charged particle beam.

5. A charged particle beam apparatus as claimed in claim 1, further comprising:

means of setting an irradiation dose target for designating an irradiation dose target at an irradiation region on said irradiation target, and
means of determining the irradiation dose for measuring the irradiation dose of the charged particle beam at said irradiation region, wherein

said extraction switching means switches on and off the extraction of the charged particle beam based on a comparison of said irradiation dose target with the irradiation dose measured by said means of determining the irradiation dose.

6. A charged particle beam apparatus as claimed in claim 1, wherein

said extraction switching means is a radio frequency applying apparatus for applying radio frequency electromagnetic field including frequency of betatron oscillation to said charged particle beam.

7. A charged particle beam apparatus as claimed in claim 1, further comprising

means of varying energy for changing energy of said charged particle beam.

8. A charged particle beam apparatus as claimed in claim 7, wherein

said means of varying energy is installed at a position between said charged particle accelerator and said irradiation target.

9. A charged particle beam apparatus comprising:

a charged particle accelerator, and
an irradiation apparatus for irradiating an irradiation target with charged particle beam supplied from said charged particle accelerator, wherein

said charged particle accelerator comprises:

an extraction switching means for switching on and off the extraction of said charged particle beam, and
said irradiation apparatus comprises:

a scatterer for enlarging the size of the charged particle beam,
electromagnets for setting an irradiation position, or an irradiation range, of said charged particle beam in order to irradiate one of plural irradiation regions, which are set in said irradiation target, with said charged particle beam, and
a control unit for changing said irradiation positi n, or said irradiation range, to another irradiation

position or range by controlling said electromagnets during said charged particle beam is switched off, wherein

said control unit changes said irradiation position or range based on said enlarged size of the charged particle beam.

10. A charged particle beam apparatus comprising:

a charged particle accelerator,
an irradiation apparatus for irradiating an irradiation target with charged particle beam supplied from said charged particle accelerator, and
a charged particle beam transport system for transporting charged particle beam extracted from said charged particle accelerator to said irradiation apparatus, wherein

said charged particle accelerator comprises:

an extraction switching means for switching on and off the extraction of said charged particle beam,
said charged particle beam transport system comprises:

a transport switching apparatus for switching transportation of and stopping the beam, and
said irradiation apparatus comprises:

a scatterer for enlarging the size of the charged particle beam,
electromagnets for setting an irradiation position, or an irradiation range, of said charged particle beam in order to irradiate one of plural irradiation regions, which are set in said irradiation target, with said charged particle beam, and
a control unit for changing said irradiation position, or an irradiation range, to another irradiation position or range based on said enlarged size of the charged particle beam during said charged particle beam is switched off in order to irradiate said another irradiation position or range with the charged particle beam.

11. A charged particle beam apparatus as claimed in any of claims 1 and 5, further comprising:

a movement monitor for detecting movement of patient, wherein

said control unit controls said extracting switching means based on the movement of the patient detected by said movement monitor.

12. A method of operating a charged particle beam apparatus for irradiating an irradiation target with charged particle beam supplied from a charged particle accelerator comprising the steps of:

enlarging size of said charged particle beam,
switching extraction of and stopping said charged particle beam, and
changing said irradiation position, or said irradiation range, during stopping said charged particle beam.

13. A method of operating a charged particle beam apparatus as claimed in claim 12, further comprising the step of:

setting an irradiation position of said charged particle beam based on said enlarged size of the charged particle beam.

14. A method of operating a charged particle beam apparatus as claimed in claim 12, wherein

said step of switching extraction of and stopping said charged particle beam further comprises the step of:

applying radio frequency electromagnetic field including frequency of betatron oscillation to said charged particle beam.

15. A charged particle beam apparatus, comprising a charged particle accelerator, for irradiating an irradiation target with charged particle beam supplied from said charged particle accelerator, further comprising:

a scatterer for enlarging the size of the charged particle beam,
an extraction means for extracting said charged particle beam,
electromagnets for setting an irradiation position or an irradiation range of said charged particle beam, and
a control unit for changing said irradiation posi-

tion or said irradiation range by controlling said electromagnets during any one of operations of injection, acceleration, and deceleration of said charged particle accelerator.

16. A charged particle beam apparatus as claimed in claim 15, wherein

said control unit changes said irradiation position or said irradiation range based on the enlarged size of the charged particle beam.

17. A charged particle beam apparatus comprising:

a charged particle accelerator, and
an irradiation apparatus for irradiating an irradiation target with charged particle beam supplied from said charged particle accelerator, wherein .

said charged particle accelerator comprises:

a kicker electromagnet for moving the charged particle beam to an extraction orbit from a circulating orbit, and
said irradiation apparatus comprises:

a scatterer for enlarging the size of the charged particle beam,
electromagnets for setting an irradiation position, or an irradiation range, of said charged particle beam in order to irradiate one of plural irradiation regions, which are set in said irradiation target, with said charged particle beam, and
a control unit for changing said irradiation position, or said irradiation range, to another irradiation position or range by controlling said electromagnets during any one of operations of injection, acceleration, and deceleration of said charged particle accelerator, wherein

said control unit changes said irradiation position or range based on said enlarged size of the charged particle beam.

18. A method of operating a charged particle beam apparatus for irradiating an irradiation target with charged particle beam supplied from a charged particle accelerator comprising the steps of:

enlarging size of said charged particle beam,
switching extraction of and stopping said charged particle beam, and
changing said irradiation position, or said irradiation range, during any one of operations of injection, acceleration, and deceleration of said charged particle accelerator.

FIG.1 (PRIOR ART)

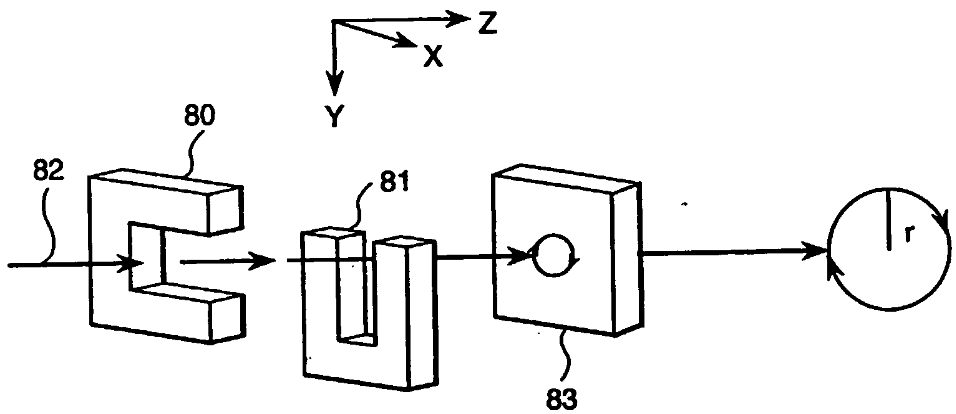


FIG.2 (PRIOR ART)

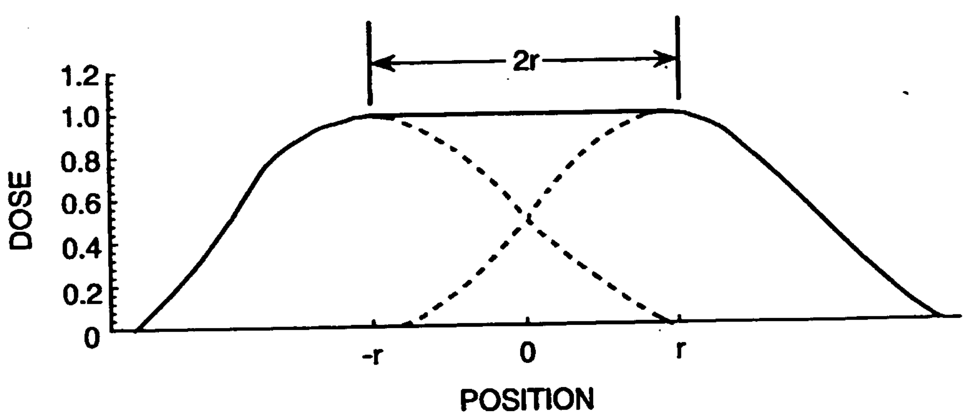
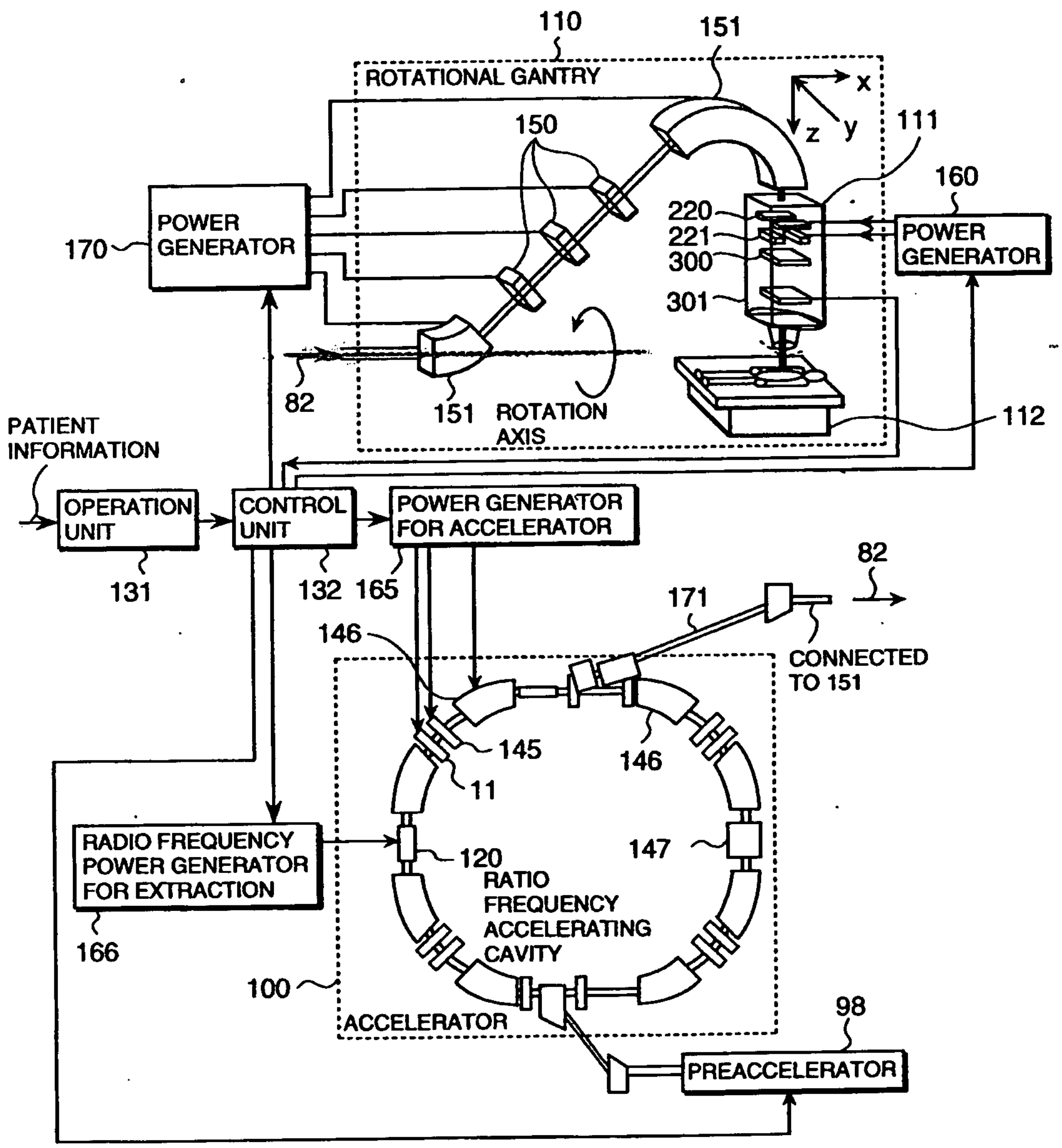


FIG.3



110
151
ROTATIONAL GANTRY
x
z
y
111
150
160
220
221
300
301
170
POWER GENERATOR
POWER GENERATOR
82
151
ROTATION AXIS
112
PATIENT INFORMATION
OPERATION UNIT
CONTROL UNIT
POWER GENERATOR FOR ACCELERATOR
131
132
165
82
171
146
CONNECTED TO 151
145
146
11
RADIO FREQUENCY POWER GENERATOR FOR EXTRACTION
120
147
RATIO FREQUENCY ACCELERATING CAVITY
166
100
ACCELERATOR
98
PREACCELERATOR

FIG.4

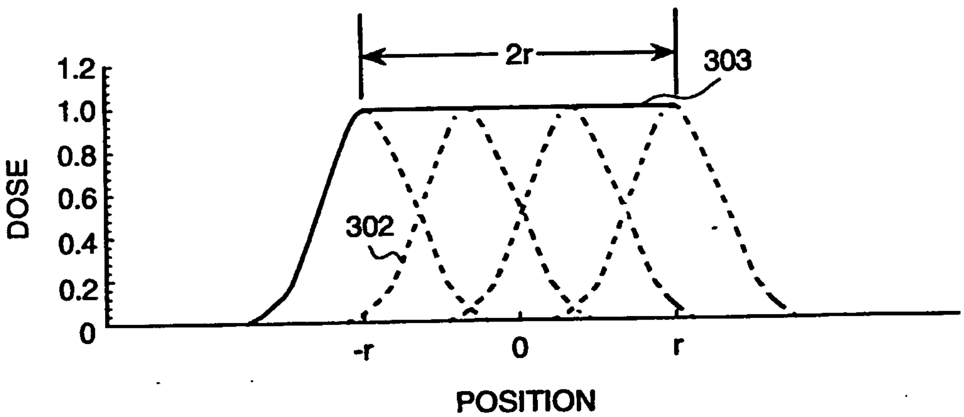

2r
303
1.2
1.0
0.8
0.6
0.4
0.2
0
DOSE
302
-r
0
r
POSITION

FIG.5

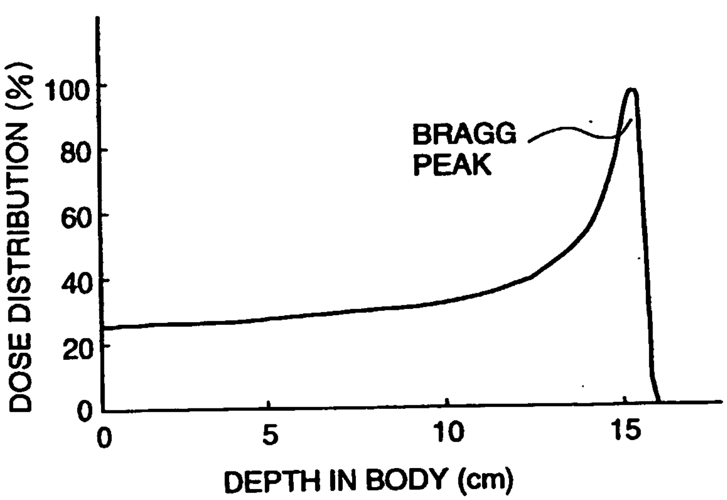

100
80
60
40
20
0
DOSE DISTRIBUTION (%)
BRAGG
PEAK
0
5
10
15
DEPTH IN BODY (cm)

FIG.6

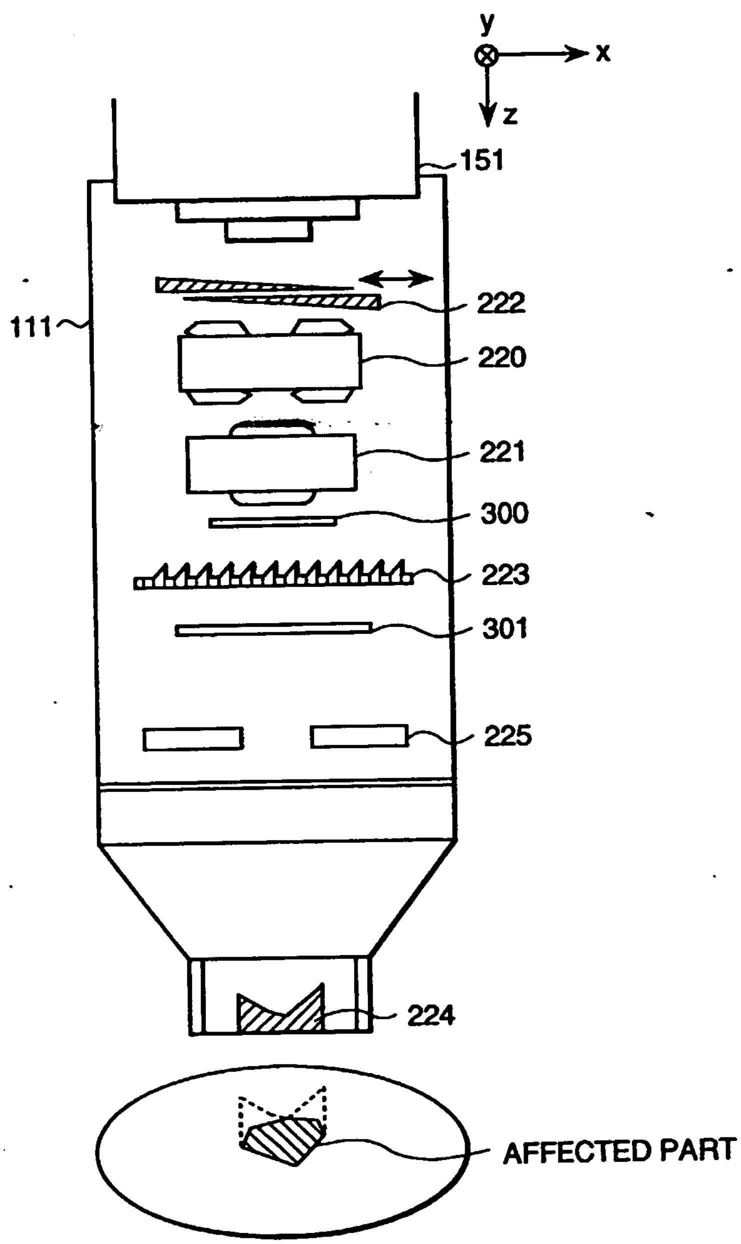


FIG.7

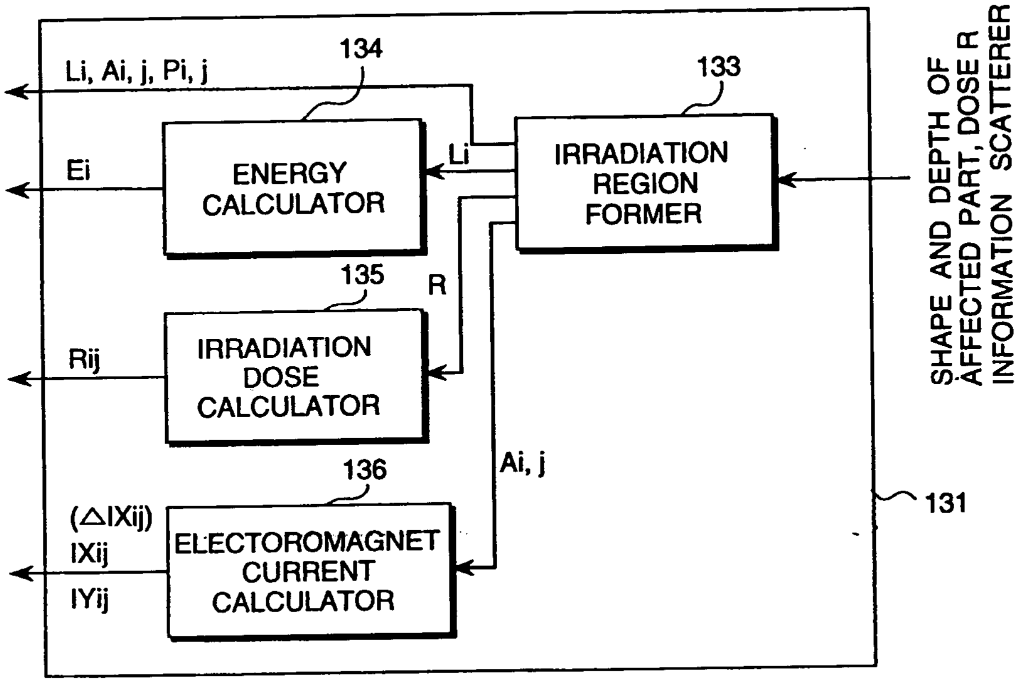

Li, Ai, j, Pi, j
134
133
Ei
ENERGY CALCULATOR
Li
IRRADIATION REGION FORMER
SHAPE AND DEPTH OF AFFECTED PART, DOSE R INFORMATION SCATTERER
135
R
Rij
IRRADIATION DOSE CALCULATOR
Ai, j
136
131
(△IXij)
IXij
IYij
ELECTOROMAGNET CURRENT CALCULATOR

FIG.8

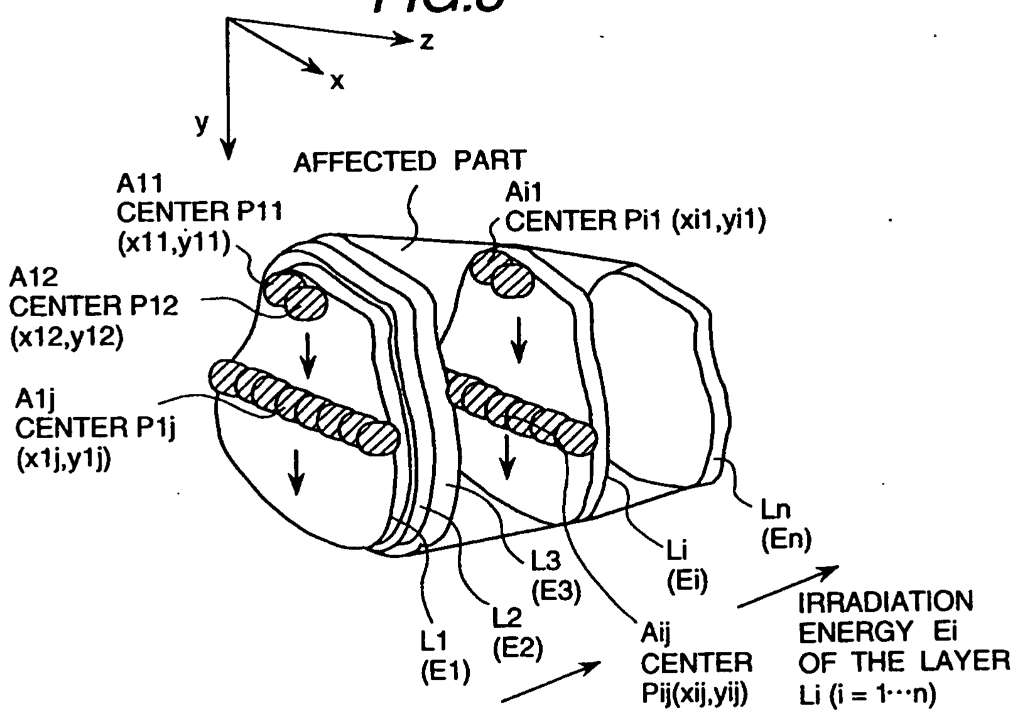

z
x
y
AFFECTED PART
A11
CENTER P11
(x11,y11)
Ai1
CENTER Pi1 (xi1,yi1)
A12
CENTER P12
(x12,y12)
A1j
CENTER P1j
(x1j,y1j)
Ln
(En)
Li
(Ei)
L3
(E3)
L2
(E2)
L1
(E1)
Aij
CENTER
Pij(xij,yij)
IRRADIATION
ENERGY Ei
OF THE LAYER
Li (i = 1···n)

FIG.9

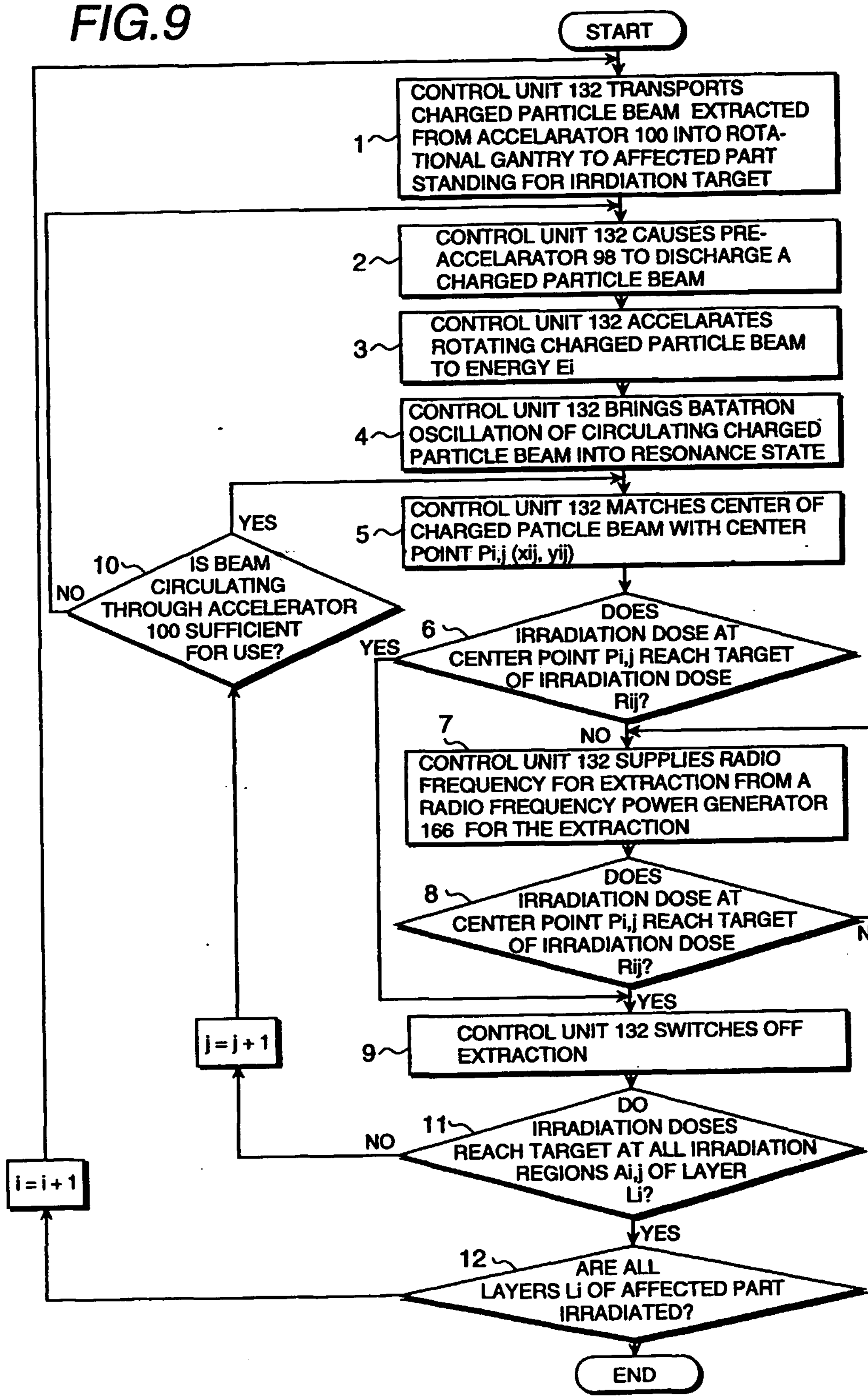

START
1
CONTROL UNIT 132 TRANSPORTS CHARGED PARTICLE BEAM EXTRACTED FROM ACCELARATOR 100 INTO ROTATIONAL GANTRY TO AFFECTED PART STANDING FOR IRRDIATION TARGET
2
CONTROL UNIT 132 CAUSES PRE-ACCELARATOR 98 TO DISCHARGE A CHARGED PARTICLE BEAM
3
CONTROL UNIT 132 ACCELARATES ROTATING CHARGED PARTICLE BEAM TO ENERGY Ei
4
CONTROL UNIT 132 BRINGS BATATRON OSCILLATION OF CIRCULATING CHARGED PARTICLE BEAM INTO RESONANCE STATE
5
CONTROL UNIT 132 MATCHES CENTER OF CHARGED PATICLE BEAM WITH CENTER POINT Pi,j (xij, yij)
10
IS BEAM CIRCULATING THROUGH ACCELERATOR 100 SUFFICIENT FOR USE?
YES
NO
6
DOES IRRADIATION DOSE AT CENTER POINT Pi,j REACH TARGET OF IRRADIATION DOSE Rij?
YES
NO
7
CONTROL UNIT 132 SUPPLIES RADIO FREQUENCY FOR EXTRACTION FROM A RADIO FREQUENCY POWER GENERATOR 166 FOR THE EXTRACTION
8
DOES IRRADIATION DOSE AT CENTER POINT Pi,j REACH TARGET OF IRRADIATION DOSE Rij?
NO
YES
j=j+1
9
CONTROL UNIT 132 SWITCHES OFF EXTRACTION
11
DO IRRADIATION DOSES REACH TARGET AT ALL IRRADIATION REGIONS Ai,j OF LAYER Li?
NO
YES
i=i+1
12
ARE ALL LAYERS Li OF AFFECTED PART IRRADIATED?
END

FIG.10

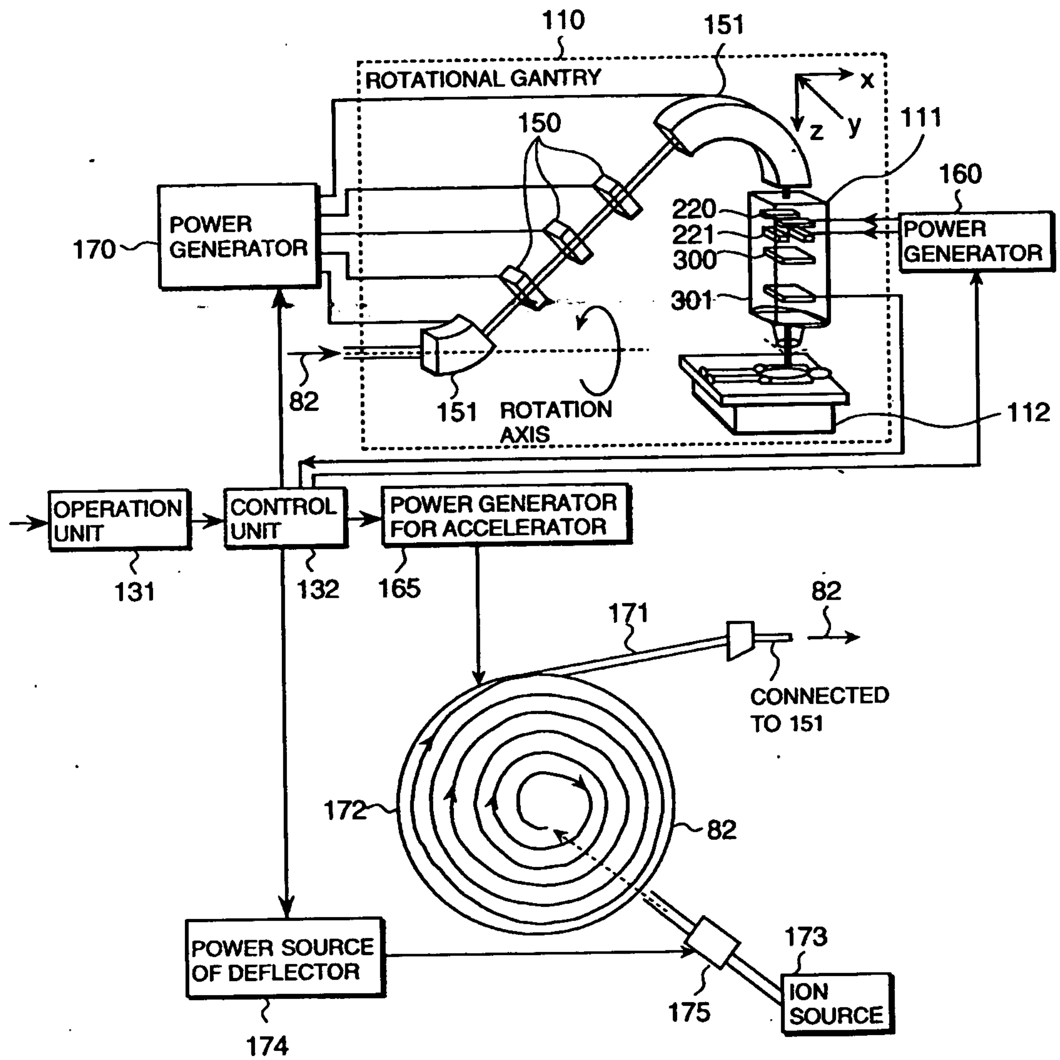

110
151
ROTATIONAL GANTRY
x
z
y
111
150
160
POWER GENERATOR
170
220
221
300
301
POWER GENERATOR
82
151
ROTATION AXIS
112
OPERATION UNIT
CONTROL UNIT
POWER GENERATOR FOR ACCELERATOR
131
132
165
82
171
CONNECTED TO 151
172
82
173
POWER SOURCE OF DEFLECTOR
175
ION SOURCE
174

FIG.11

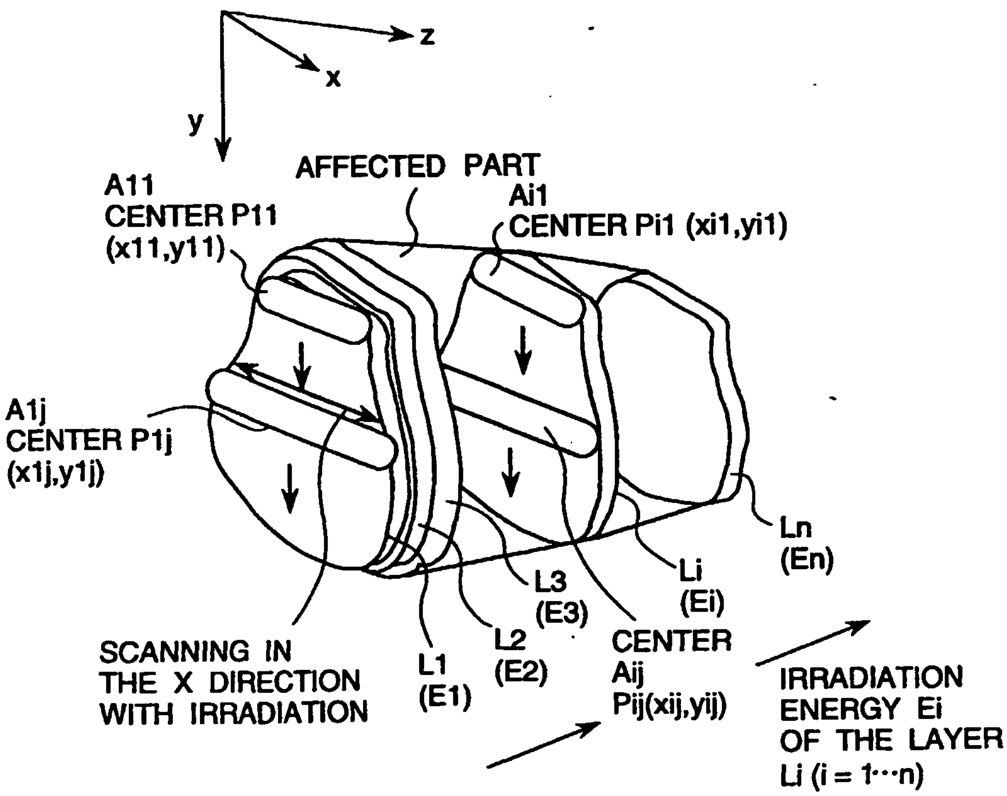

z
x
y
AFFECTED PART
A11
CENTER P11
(x11,y11)
Ai1
CENTER Pi1 (xi1,yi1)
A1j
CENTER P1j
(x1j,y1j)
Ln
(En)
Li
(Ei)
L3
(E3)
L2
(E2)
L1
(E1)
CENTER
Aij
Pij(xij,yij)
SCANNING IN
THE X DIRECTION
WITH IRRADIATION
IRRADIATION
ENERGY Ei
OF THE LAYER
Li (i = 1···n)

FIG.12

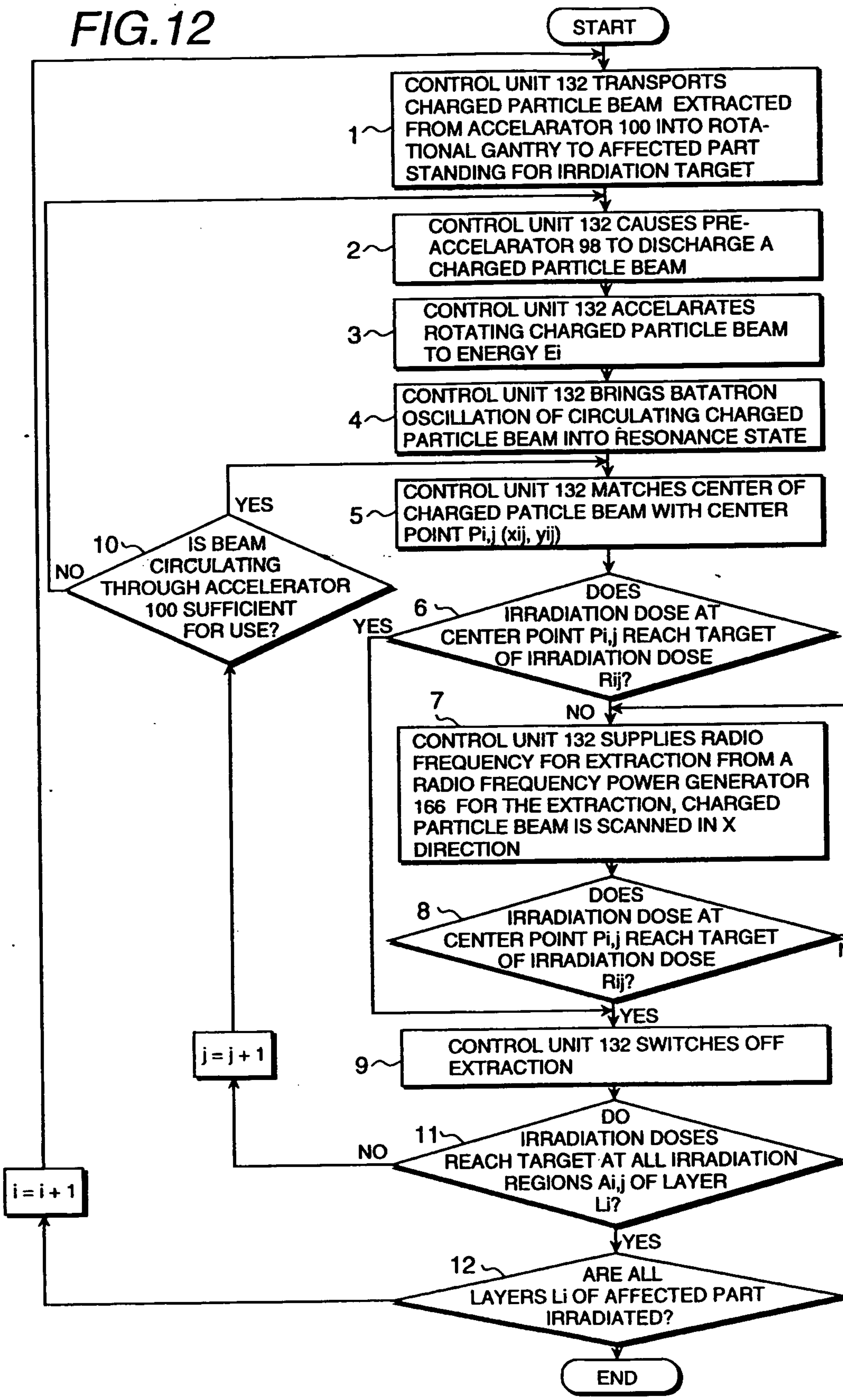

START
1
CONTROL UNIT 132 TRANSPORTS CHARGED PARTICLE BEAM EXTRACTED FROM ACCELARATOR 100 INTO ROTATIONAL GANTRY TO AFFECTED PART STANDING FOR IRRDIATION TARGET
2
CONTROL UNIT 132 CAUSES PRE-ACCELARATOR 98 TO DISCHARGE A CHARGED PARTICLE BEAM
3
CONTROL UNIT 132 ACCELARATES ROTATING CHARGED PARTICLE BEAM TO ENERGY Ei
4
CONTROL UNIT 132 BRINGS BATATRON OSCILLATION OF CIRCULATING CHARGED PARTICLE BEAM INTO RESONANCE STATE
5
CONTROL UNIT 132 MATCHES CENTER OF CHARGED PATICLE BEAM WITH CENTER POINT Pi,j (xij, yij)
10
IS BEAM CIRCULATING THROUGH ACCELERATOR 100 SUFFICIENT FOR USE?
YES
NO
6
DOES IRRADIATION DOSE AT CENTER POINT Pi,j REACH TARGET OF IRRADIATION DOSE Rij?
YES
NO
7
CONTROL UNIT 132 SUPPLIES RADIO FREQUENCY FOR EXTRACTION FROM A RADIO FREQUENCY POWER GENERATOR 166 FOR THE EXTRACTION, CHARGED PARTICLE BEAM IS SCANNED IN X DIRECTION
8
DOES IRRADIATION DOSE AT CENTER POINT Pi,j REACH TARGET OF IRRADIATION DOSE Rij?
NO
YES
9
CONTROL UNIT 132 SWITCHES OFF EXTRACTION
j = j + 1
11
DO IRRADIATION DOSES REACH TARGET AT ALL IRRADIATION REGIONS Ai,j OF LAYER Li?
NO
YES
i = i + 1
12
ARE ALL LAYERS Li OF AFFECTED PART IRRADIATED?
END

FIG. 13

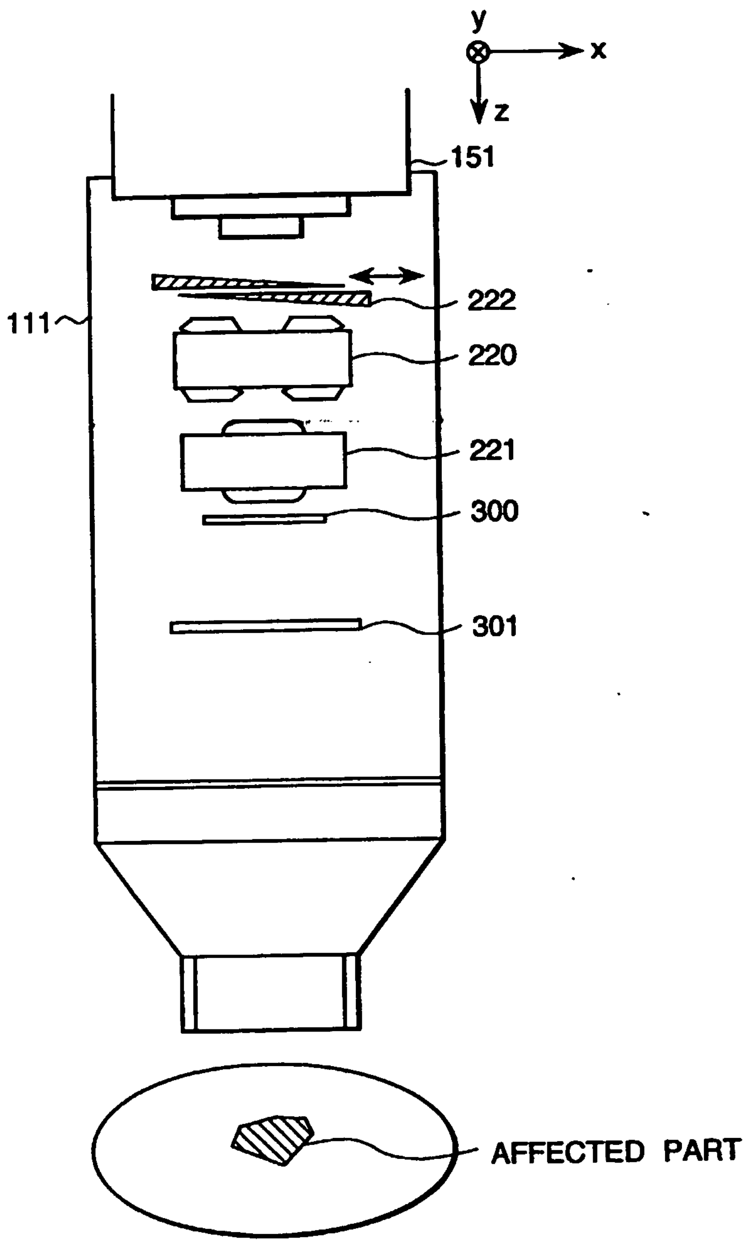


FIG.14

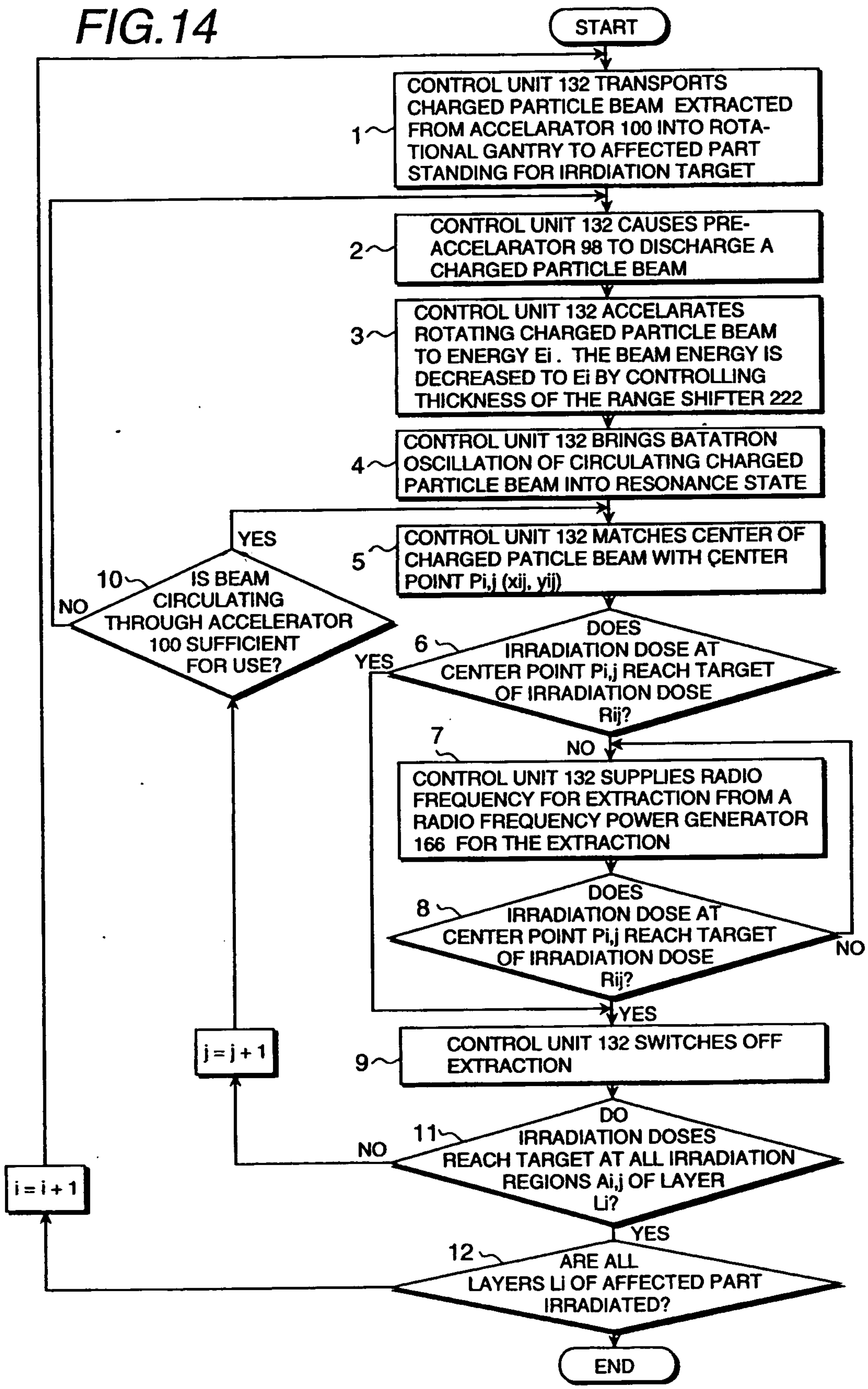

START
CONTROL UNIT 132 TRANSPORTS CHARGED PARTICLE BEAM EXTRACTED FROM ACCELARATOR 100 INTO ROTATIONAL GANTRY TO AFFECTED PART STANDING FOR IRRDIATION TARGET
1
CONTROL UNIT 132 CAUSES PRE-ACCELARATOR 98 TO DISCHARGE A CHARGED PARTICLE BEAM
2
CONTROL UNIT 132 ACCELARATES ROTATING CHARGED PARTICLE BEAM TO ENERGY Ei . THE BEAM ENERGY IS DECREASED TO Ei BY CONTROLLING THICKNESS OF THE RANGE SHIFTER 222
3
CONTROL UNIT 132 BRINGS BATATRON OSCILLATION OF CIRCULATING CHARGED PARTICLE BEAM INTO RESONANCE STATE
4
CONTROL UNIT 132 MATCHES CENTER OF CHARGED PATICLE BEAM WITH ÇENTER POINT Pi,j (xij, yij)
5
IS BEAM CIRCULATING THROUGH ACCELERATOR 100 SUFFICIENT FOR USE?
10
YES
NO
DOES IRRADIATION DOSE AT CENTER POINT Pi,j REACH TARGET OF IRRADIATION DOSE Rij?
6
YES
NO
7
CONTROL UNIT 132 SUPPLIES RADIO FREQUENCY FOR EXTRACTION FROM A RADIO FREQUENCY POWER GENERATOR 166 FOR THE EXTRACTION
DOES IRRADIATION DOSE AT CENTER POINT Pi,j REACH TARGET OF IRRADIATION DOSE Rij?
8
NO
YES
j = j + 1
CONTROL UNIT 132 SWITCHES OFF EXTRACTION
9
DO IRRADIATION DOSES REACH TARGET AT ALL IRRADIATION REGIONS Ai,j OF LAYER Li?
11
NO
YES
i = i + 1
ARE ALL LAYERS Li OF AFFECTED PART IRRADIATED?
12
END

FIG.15

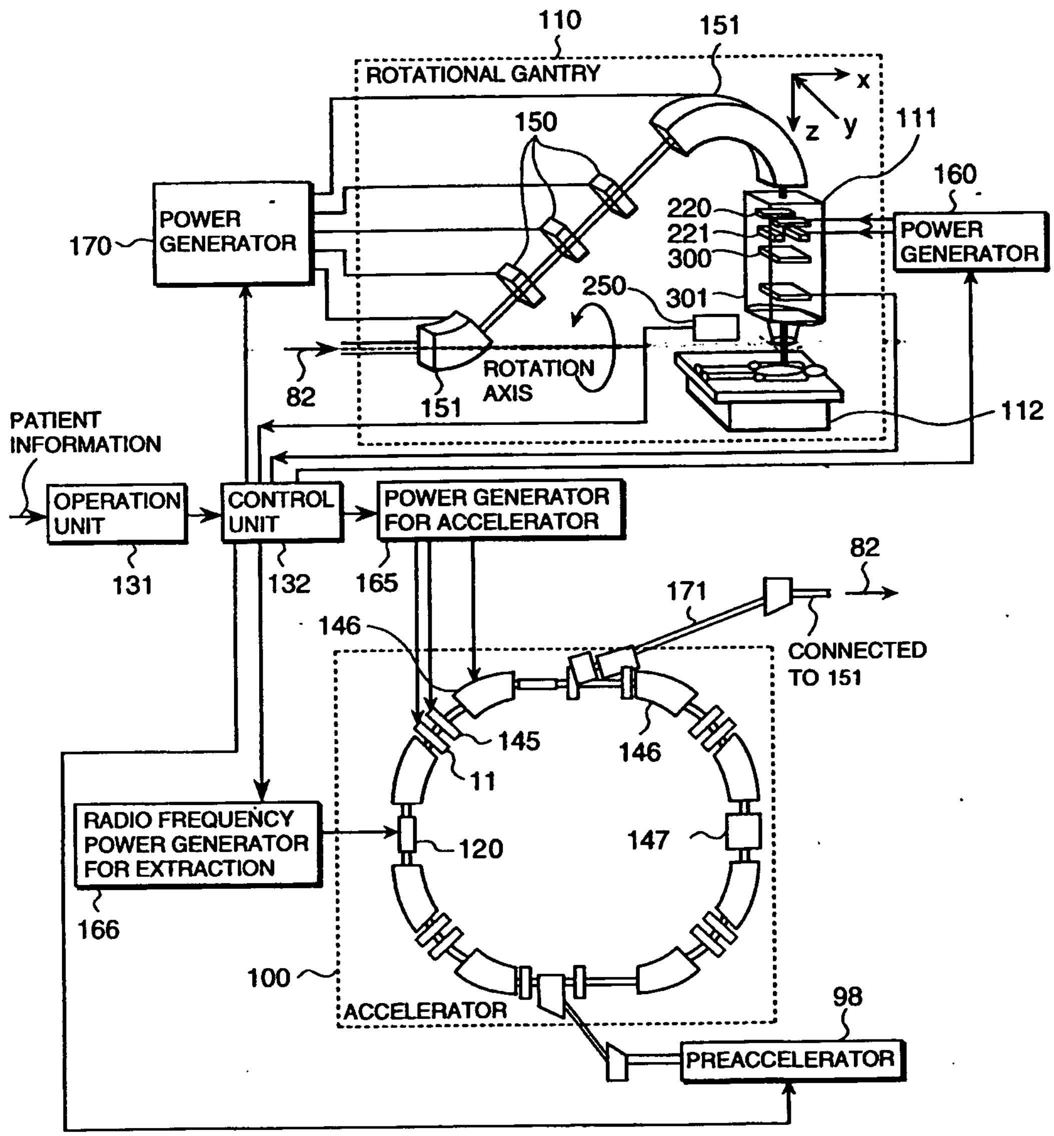

110
151
ROTATIONAL GANTRY
x
z
y
111
150
160
POWER GENERATOR
220
221
300
POWER GENERATOR
170
250
301
ROTATION AXIS
82
151
112
PATIENT INFORMATION
OPERATION UNIT
CONTROL UNIT
POWER GENERATOR FOR ACCELERATOR
131
132
165
82
171
146
CONNECTED TO 151
145
146
11
RADIO FREQUENCY POWER GENERATOR FOR EXTRACTION
120
147
166
100
ACCELERATOR
98
PREACCELERATOR

FIG.16

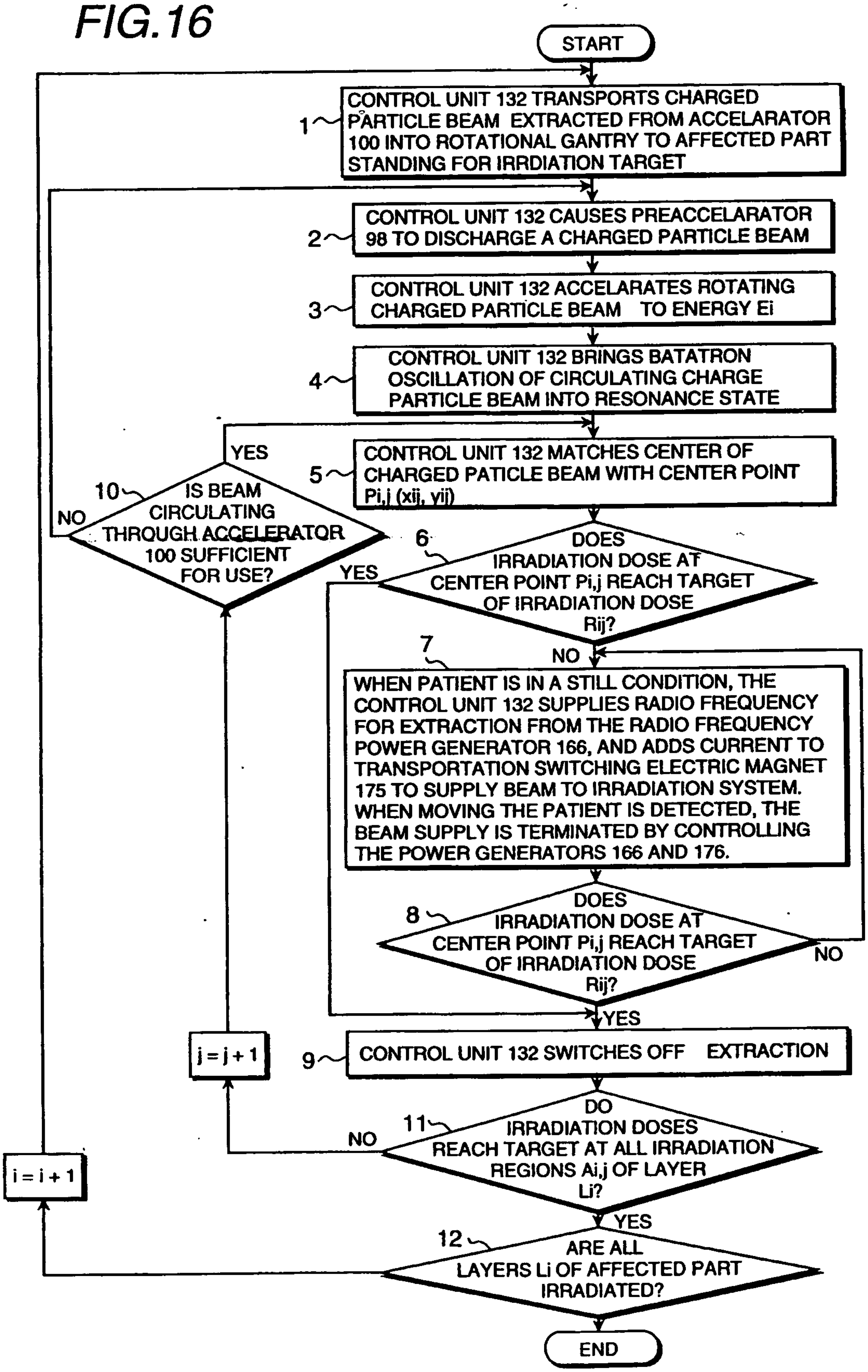

START
1 CONTROL UNIT 132 TRANSPORTS CHARGED PARTICLE BEAM EXTRACTED FROM ACCELARATOR 100 INTO ROTATIONAL GANTRY TO AFFECTED PART STANDING FOR IRRDIATION TARGET
2 CONTROL UNIT 132 CAUSES PREACCELARATOR 98 TO DISCHARGE A CHARGED PARTICLE BEAM
3 CONTROL UNIT 132 ACCELARATES ROTATING CHARGED PARTICLE BEAM TO ENERGY Ei
4 CONTROL UNIT 132 BRINGS BATATRON OSCILLATION OF CIRCULATING CHARGE PARTICLE BEAM INTO RESONANCE STATE
5 CONTROL UNIT 132 MATCHES CENTER OF CHARGED PATICLE BEAM WITH CENTER POINT Pi,j (xij, yij)
6 DOES IRRADIATION DOSE AT CENTER POINT Pi,j REACH TARGET OF IRRADIATION DOSE Rij?
YES
NO
7 WHEN PATIENT IS IN A STILL CONDITION, THE CONTROL UNIT 132 SUPPLIES RADIO FREQUENCY FOR EXTRACTION FROM THE RADIO FREQUENCY POWER GENERATOR 166, AND ADDS CURRENT TO TRANSPORTATION SWITCHING ELECTRIC MAGNET 175 TO SUPPLY BEAM TO IRRADIATION SYSTEM. WHEN MOVING THE PATIENT IS DETECTED, THE BEAM SUPPLY IS TERMINATED BY CONTROLLING THE POWER GENERATORS 166 AND 176.
8 DOES IRRADIATION DOSE AT CENTER POINT Pi,j REACH TARGET OF IRRADIATION DOSE Rij?
NO
YES
9 CONTROL UNIT 132 SWITCHES OFF EXTRACTION
10 IS BEAM CIRCULATING THROUGH ACCELERATOR 100 SUFFICIENT FOR USE?
YES
NO
j = j + 1
11 DO IRRADIATION DOSES REACH TARGET AT ALL IRRADIATION REGIONS Ai,j OF LAYER Li?
NO
YES
i = i + 1
12 ARE ALL LAYERS Li OF AFFECTED PART IRRADIATED?
END

FIG.17

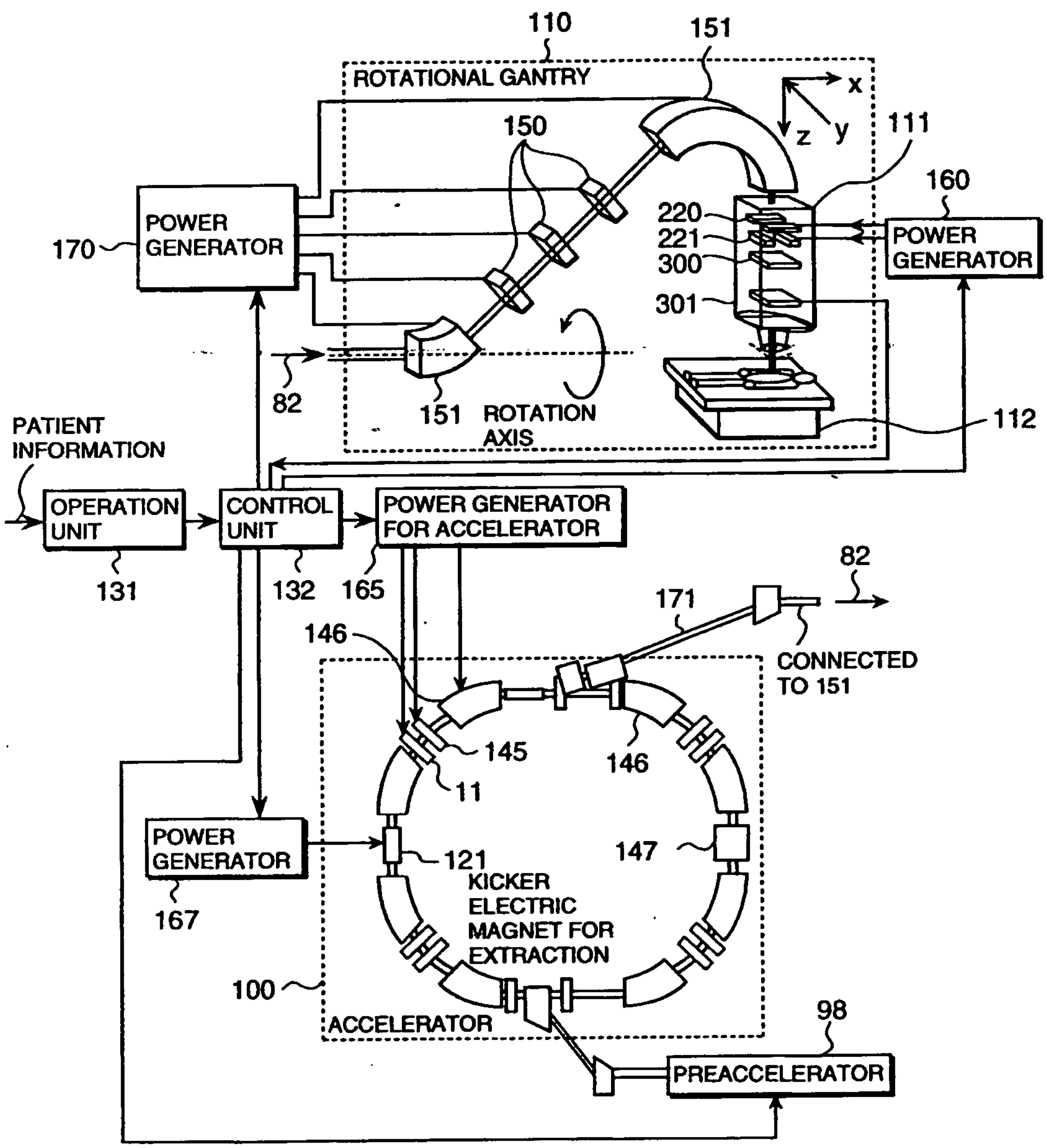
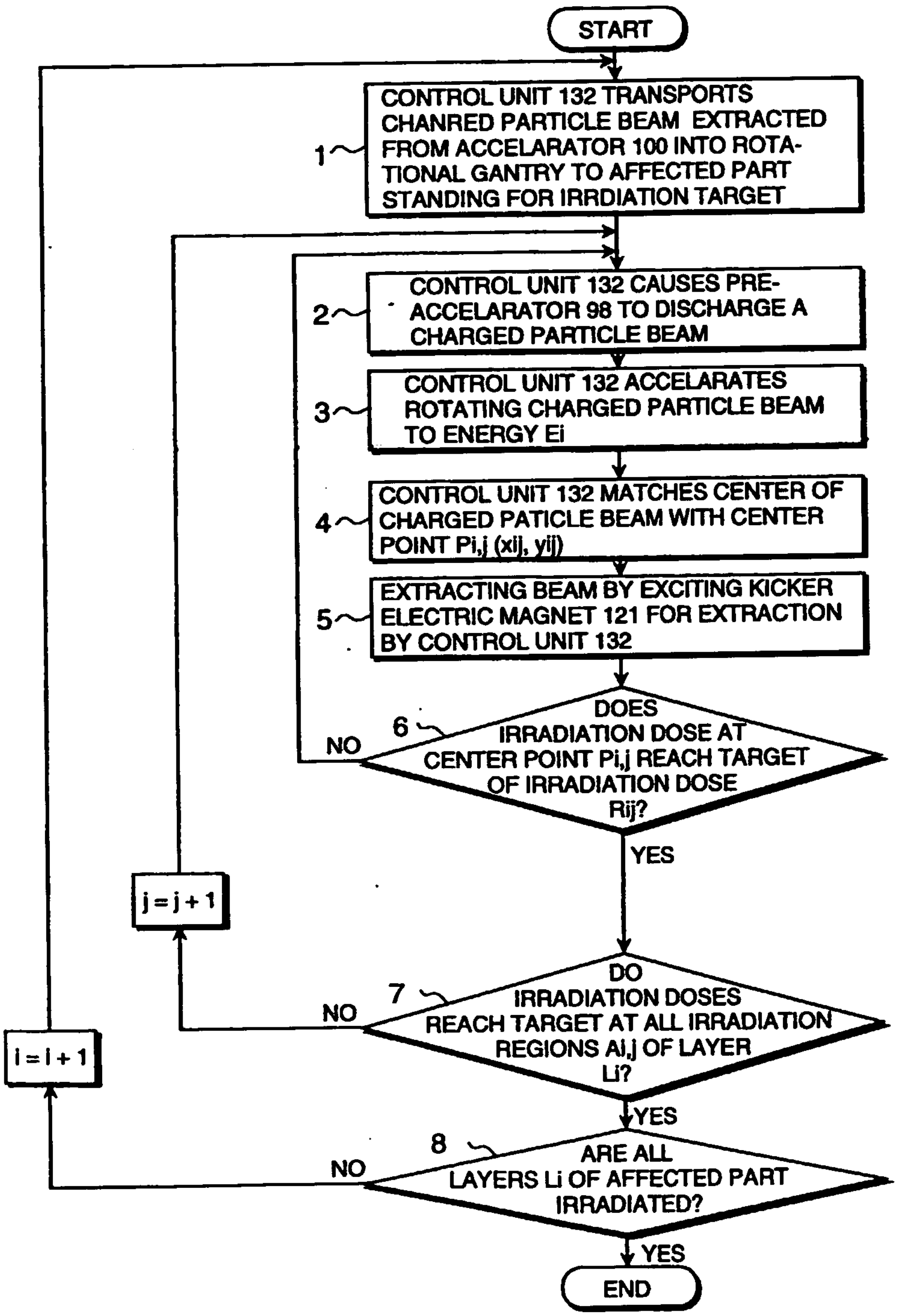

110
151
ROTATIONAL GANTRY
x
z
y
111
150
160
POWER GENERATOR
170
220
221
300
301
POWER GENERATOR
82
151
ROTATION AXIS
112
PATIENT INFORMATION
OPERATION UNIT
CONTROL UNIT
POWER GENERATOR FOR ACCELERATOR
131
132
165
82
171
146
CONNECTED TO 151
145
146
11
POWER GENERATOR
121
147
KICKER ELECTRIC MAGNET FOR EXTRACTION
167
100
ACCELERATOR
98
PREACCELERATOR

FIG.18


START
1
CONTROL UNIT 132 TRANSPORTS CHANRED PARTICLE BEAM EXTRACTED FROM ACCELARATOR 100 INTO ROTATIONAL GANTRY TO AFFECTED PART STANDING FOR IRRDIATION TARGET
2
CONTROL UNIT 132 CAUSES PRE-ACCELARATOR 98 TO DISCHARGE A CHARGED PARTICLE BEAM
3
CONTROL UNIT 132 ACCELARATES ROTATING CHARGED PARTICLE BEAM TO ENERGY Ei
4
CONTROL UNIT 132 MATCHES CENTER OF CHARGED PATICLE BEAM WITH CENTER POINT Pi,j (xij, yij)
5
EXTRACTING BEAM BY EXCITING KICKER ELECTRIC MAGNET 121 FOR EXTRACTION BY CONTROL UNIT 132
6
DOES IRRADIATION DOSE AT CENTER POINT Pi,j REACH TARGET OF IRRADIATION DOSE Rij?
NO
YES
j = j + 1
7
DO IRRADIATION DOSES REACH TARGET AT ALL IRRADIATION REGIONS Ai,j OF LAYER Li?
NO
YES
i = i + 1
8
ARE ALL LAYERS Li OF AFFECTED PART IRRADIATED?
NO
YES
END